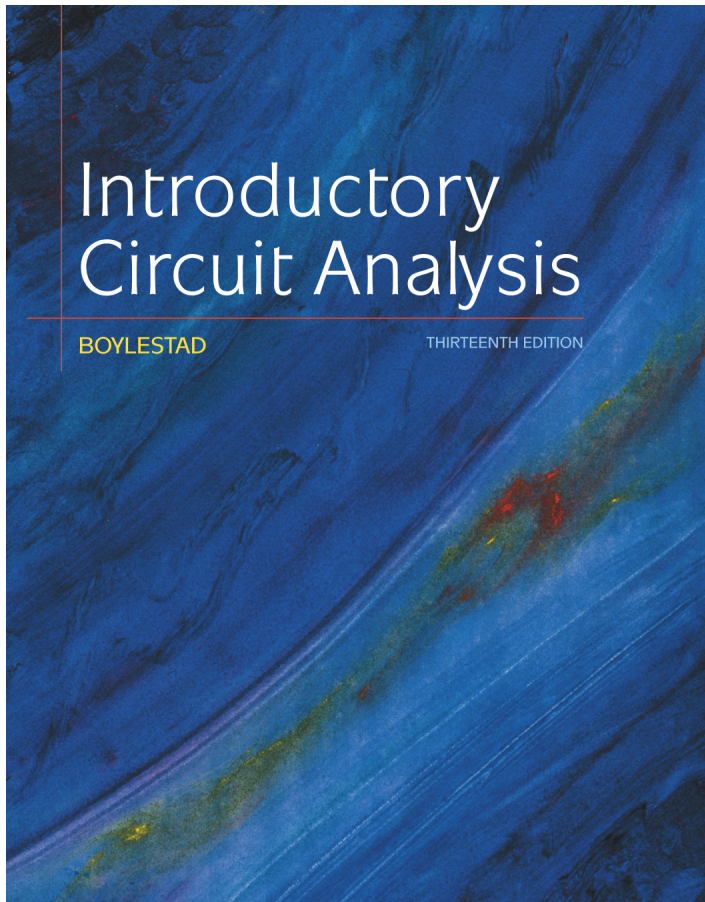


Introductory Circuit Analysis



CHAPTER 3

Resistance

OBJECTIVES

- Become familiar with the parameters that determine the resistance of an element and be able to calculate the resistance from the given dimensions and material characteristics.
- Understand the effects of temperature on the resistance of a material and how to calculate the change in resistance with temperature.

OBJECTIVES

- Develop some understanding of superconductors and how they can affect future development in the industry.
- Become familiar with the broad range of commercially available resistors available today and how to read the value of each from the color code or labeling.

OBJECTIVES

- Become aware of a variety of elements such as thermistors, photoconductive cells, and varistors and how their terminal resistance is controlled.

INTRODUCTION

- This opposition to the flow of charge through an electrical circuit, called resistance, has the units of ohms and uses the Greek letter omega (Ω) as its symbol.
- The graphic symbol for resistance, which resembles the cutting edge of a saw.

INTRODUCTION

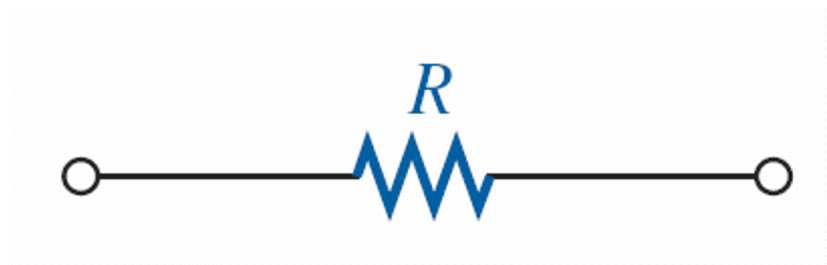


FIG. 3.1 *Resistance symbol and notation.*

INTRODUCTION

- This opposition, due primarily to collisions and friction between the free electrons and other electrons, ions, and atoms in the path of motion, converts the supplied electrical energy into heat that raises the temperature of the electrical component and surrounding medium.

INTRODUCTION

- The heat you feel from an electrical heater is simply due to current passing through a high-resistance material.

RESISTANCE: CIRCULAR WIRES

- The resistance of any material is due primarily to four factors:
 - Material
 - Length
 - Cross-sectional area
 - Temperature of the material
- The atomic structure determines how easily a free electron will pass through a material.

RESISTANCE: CIRCULAR WIRES

- The longer the path through which the free electron must pass, the greater is the resistance factor.
- Free electrons pass more easily through conductors with larger crosssectional areas.

RESISTANCE: CIRCULAR WIRES

- In addition, the higher the temperature of the conductive materials, the greater is the internal vibration and motion of the components that make up the atomic structure of the wire, and the more difficult it is for the free electrons to find a path through the material.

RESISTANCE: CIRCULAR WIRES

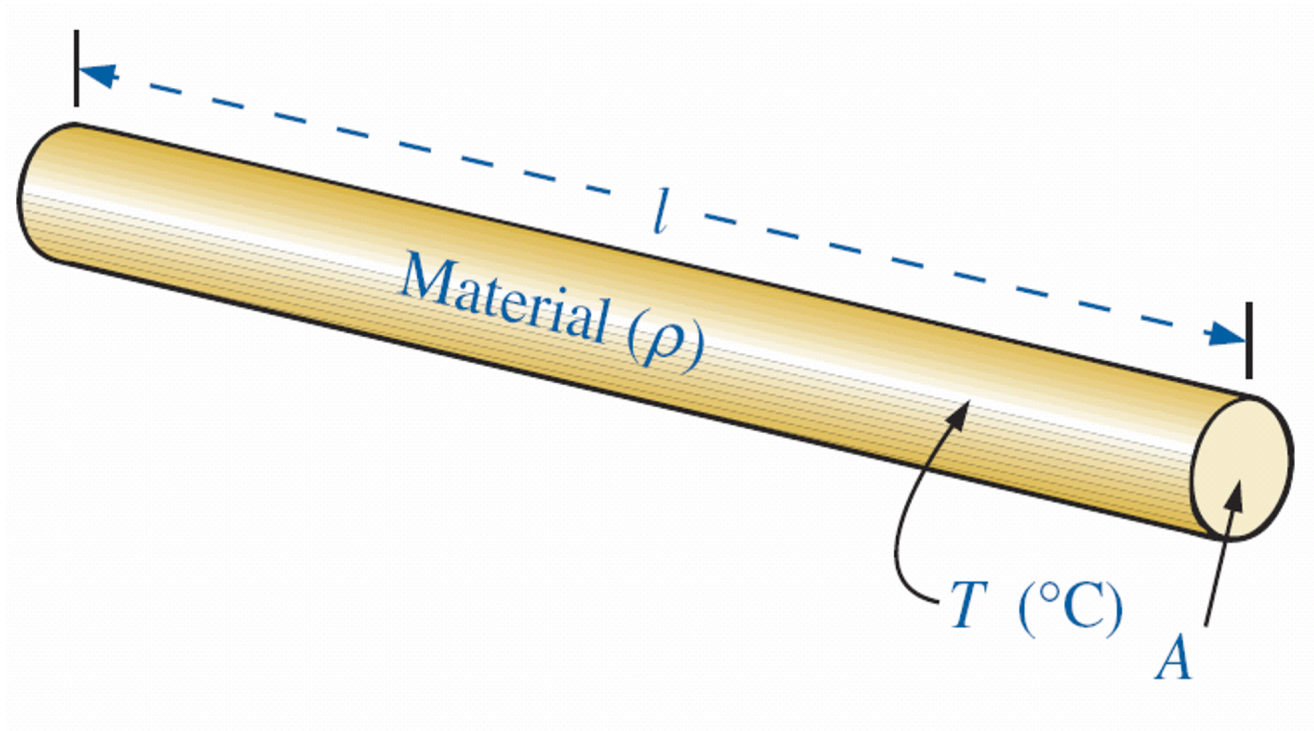


FIG. 3.2 *Factors affecting the resistance of a conductor.*

RESISTANCE: CIRCULAR WIRES

Material	ρ (CM- Ω /ft)@20°C
Silver	9.9
Copper	10.37
Gold	14.7
Aluminum	17.0
Tungsten	33.0
Nickel	47.0
Iron	74.0
Constantan	295.0
Nichrome	600.0
Calorite	720.0
Carbon	21,000.0

TABLE 3.1 *Resistivity (ρ) of various materials.*

RESISTANCE: CIRCULAR WIRES

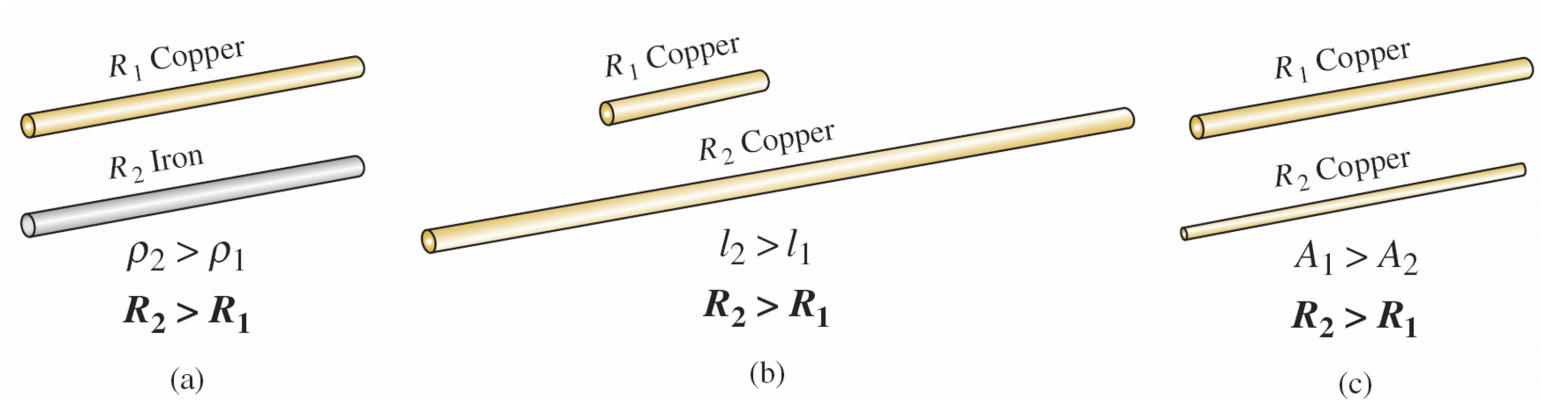


FIG. 3.3 Cases in which $R_2 > R_1$. For each case, all remaining parameters that control the resistance level are the same.

RESISTANCE: CIRCULAR WIRES

Circular Mils (CM)

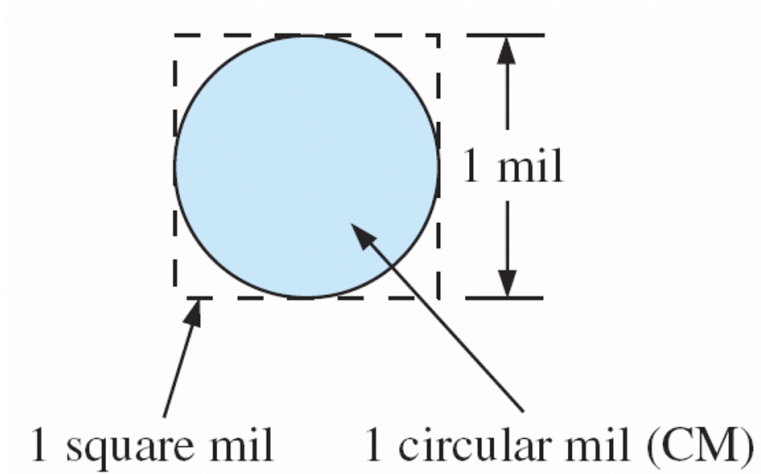


FIG. 3.4 *Defining the circular mil (CM).*

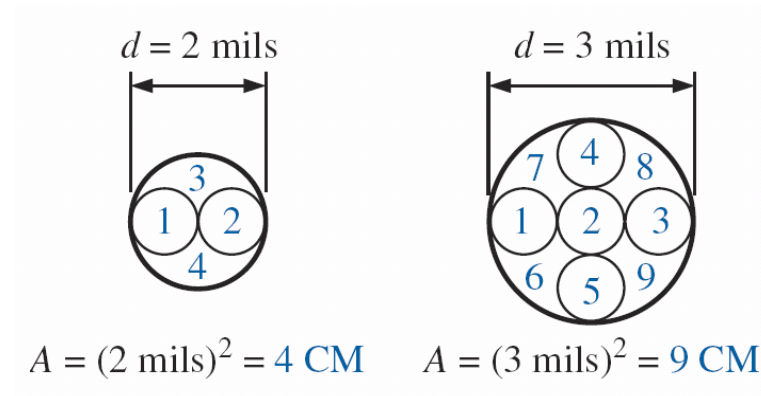


FIG. 3.5 *Verification of Eq. (3.2): $A_{CM} = (d_{mils})^2$.*

RESISTANCE: CIRCULAR WIRES

Circular Mils (CM)

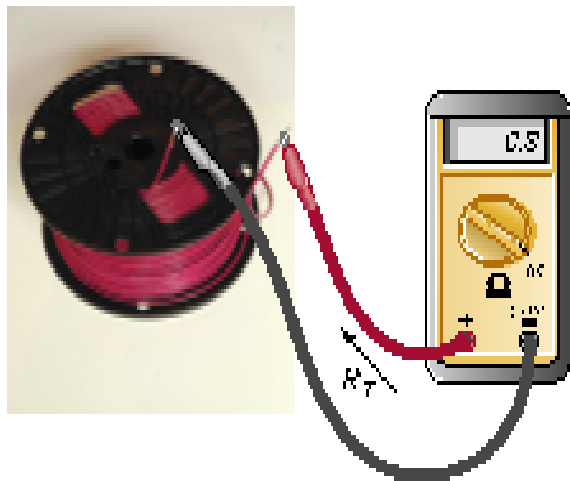


FIG. 3.6

Example 3.2.
(Don Johnson
Photo)

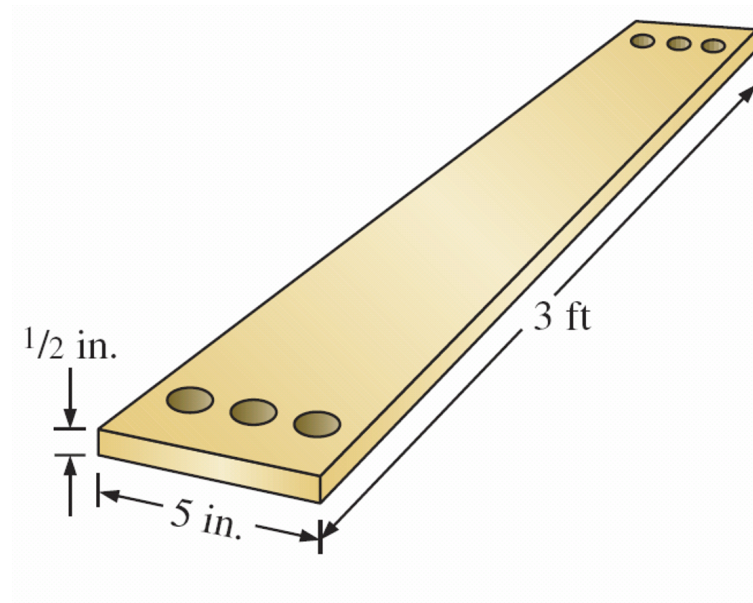


FIG. 3.7

Example 3.3.

WIRE TABLES

- The wire table was designed primarily to standardize the size of wire produced by manufacturers.
- As a result, the manufacturer has a larger market, and the consumer knows that standard wire sizes will always be available.

WIRE TABLES

- The table was designed to assist the user in every way possible; it usually includes data such as the cross-sectional area in circular mils, diameter in mils, ohms per 1000 feet at 20°C, and weight per 1000 feet.

WIRE TABLES

AWG #	Area (CM)	$\Omega/1000$ ft at 20°C	Maximum Allowable Current for RHW Insulation (A)*
(4/0) 0000	211,600	0.0490	230
(3/0) 000	167,810	0.0618	200
(2/0) 00	133,080	0.0780	175
(1/0) 0	105,530	0.0983	150
1	83,694	0.1240	130
2	66,373	0.1563	115
3	52,634	0.1970	100
4	41,742	0.2485	85
5	33,102	0.3133	—
6	26,250	0.3951	65
7	20,816	0.4982	—
8	16,509	0.6282	50
9	13,094	0.7921	—
10	10,381	0.9989	30
11	8,234.0	1.260	—
12	6,529.9	1.588	20
13	5,178.4	2.003	—
14	4,106.8	2.525	15
15	3,256.7	3.184	—
16	2,582.9	4.016	—
17	2,048.2	5.064	—
18	1,624.3	6.385	—
19	1,288.1	8.051	—
20	1,021.5	10.15	—
21	810.10	12.80	—
22	642.40	16.14	—
23	509.45	20.36	—
24	404.01	25.67	—
25	320.40	32.37	—
26	254.10	40.81	—
27	201.50	51.47	—
28	159.79	64.90	—
29	126.72	81.83	—
30	100.50	103.2	—
31	79.70	130.1	—
32	63.21	164.1	—
33	50.13	206.9	—
34	39.75	260.9	—
35	31.52	329.0	—
36	25.00	414.8	—
37	19.83	523.1	—
38	15.72	659.6	—
39	12.47	831.8	—
40	9.89	1049.0	—

TABLE 3.2
*American Wire
Gage (AWG)
sizes.*

WIRE TABLES

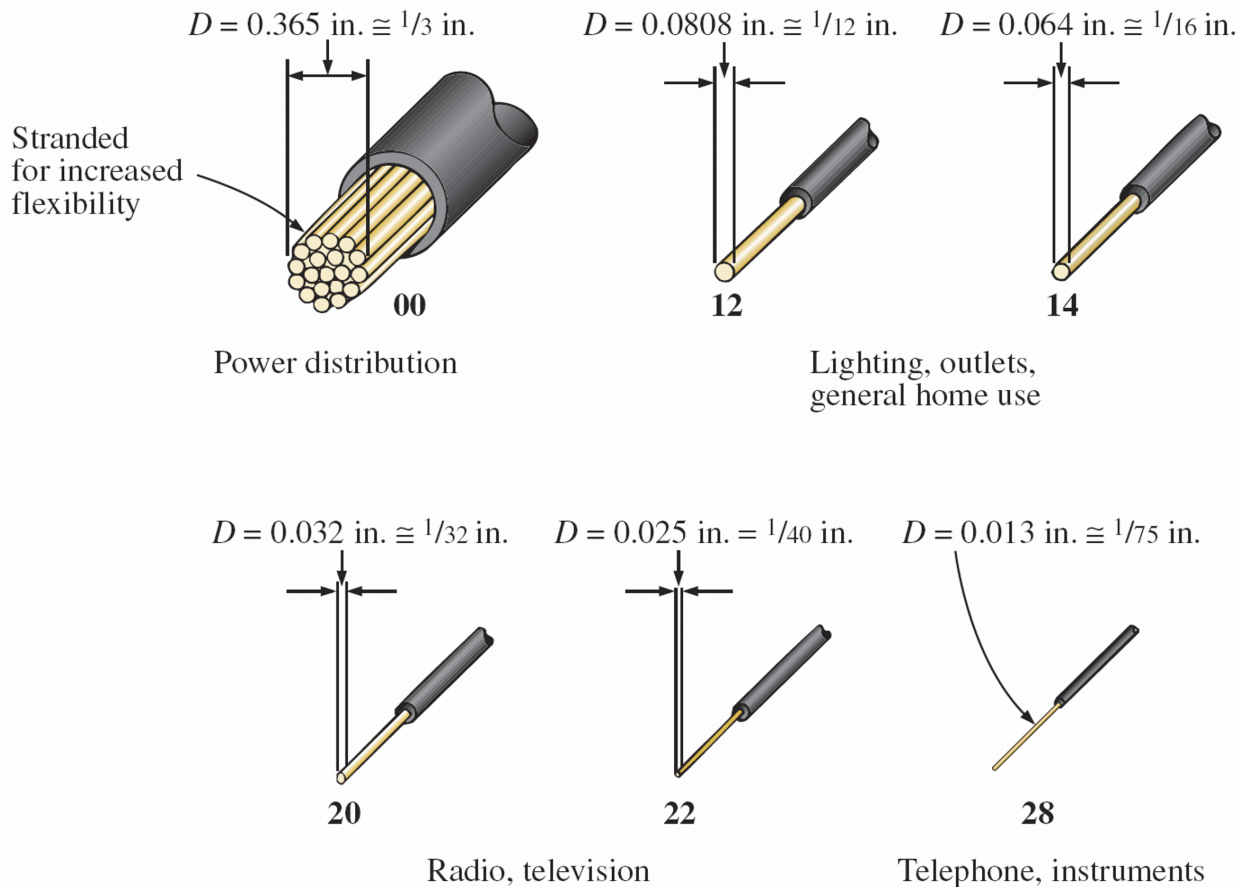


FIG. 3.8 Popular wire sizes and some of their areas of application.

WIRE TABLES

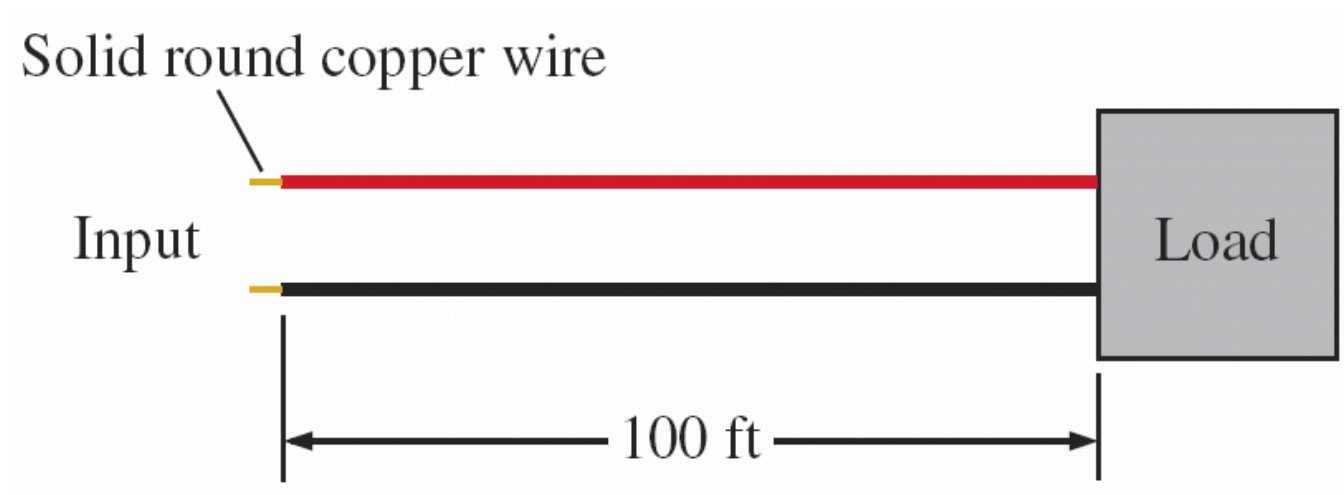


FIG. 3.9
Example
3.6.

TEMPERATURE EFFECTS

- Temperature has a significant effect on the resistance of conductors, semiconductors, and insulators.
 - Conductors
 - Semiconductors
 - Insulators
 - Inferred Absolute Temperature
 - Temperature Coefficient of Resistance
 - PPM/°C

TEMPERATURE EFFECTS

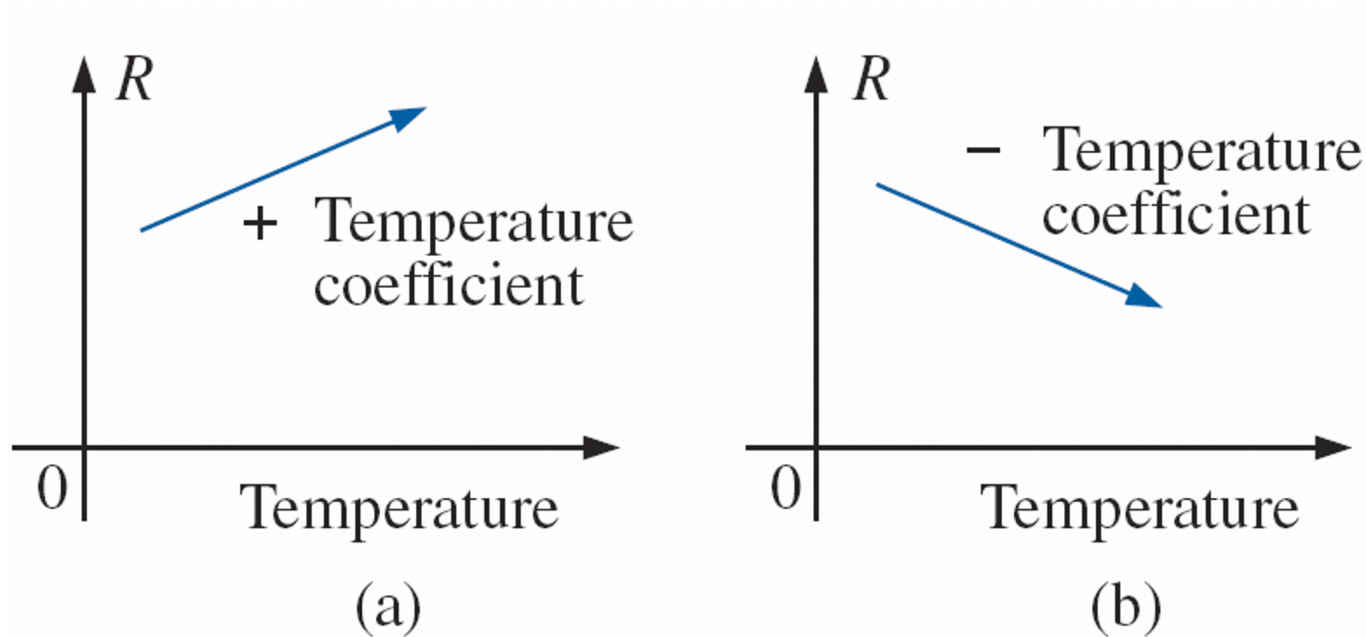


FIG. 3.10 *Demonstrating the effect of a positive and a negative temperature coefficient on the resistance of a conductor.*

TEMPERATURE EFFECTS

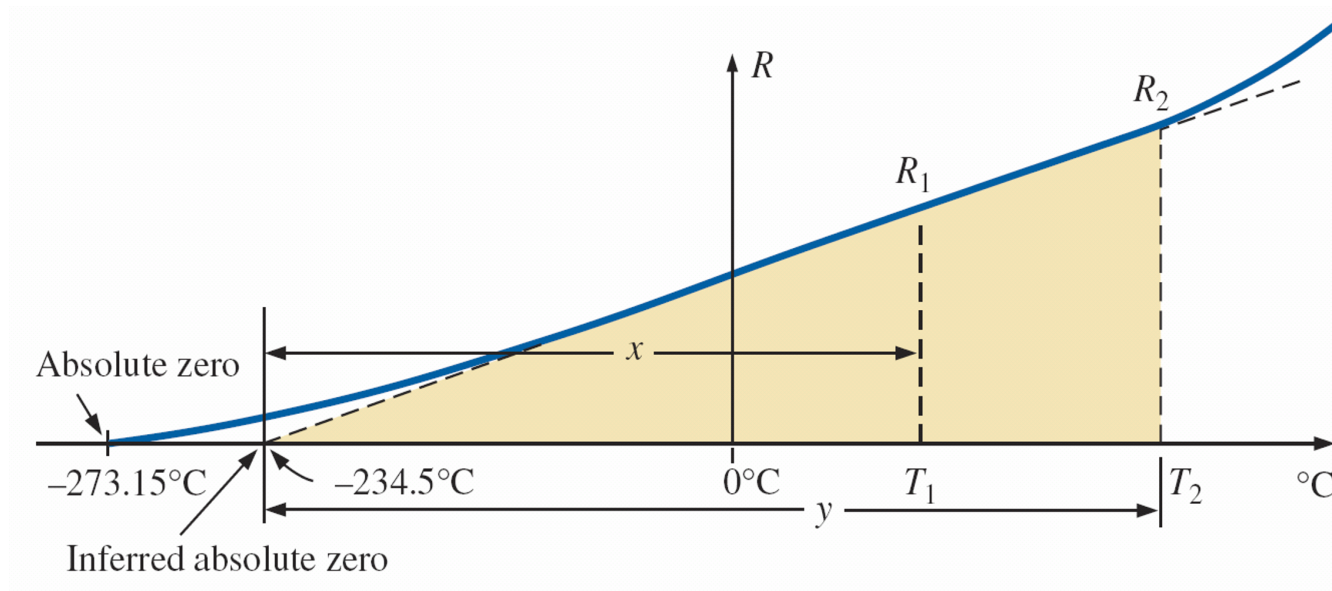


FIG. 3.11 *Effect of temperature on the resistance of copper.*

TEMPERATURE EFFECTS

Material	°C
Silver	– 243
Copper	– 234.5
Gold	– 274
Aluminum	– 236
Tungsten	– 204
Nickel	– 147
Iron	– 162
Nichrome	– 2,250
Constantan	– 125,000

TABLE 3.3 *Inferred absolute temperatures (T_i).*

TEMPERATURE EFFECTS

Material	Temperature Coefficient (α_{20})
Silver	0.0038
Copper	0.00393
Gold	0.0034
Aluminum	0.00391
Tungsten	0.005
Nickel	0.006
Iron	0.0055
Constantan	0.000008
Nichrome	0.00044

TABLE 3.4 *Temperature coefficient of resistance for various conductors at 20°C.*

TYPES OF RESISTORS

Fixed Resistors

- Resistors are made in many forms, but all belong in either of two groups: fixed or variable.
- The most common of the low-wattage, fixedtype resistors is the film resistor.

TYPES OF RESISTORS

Fixed Resistors

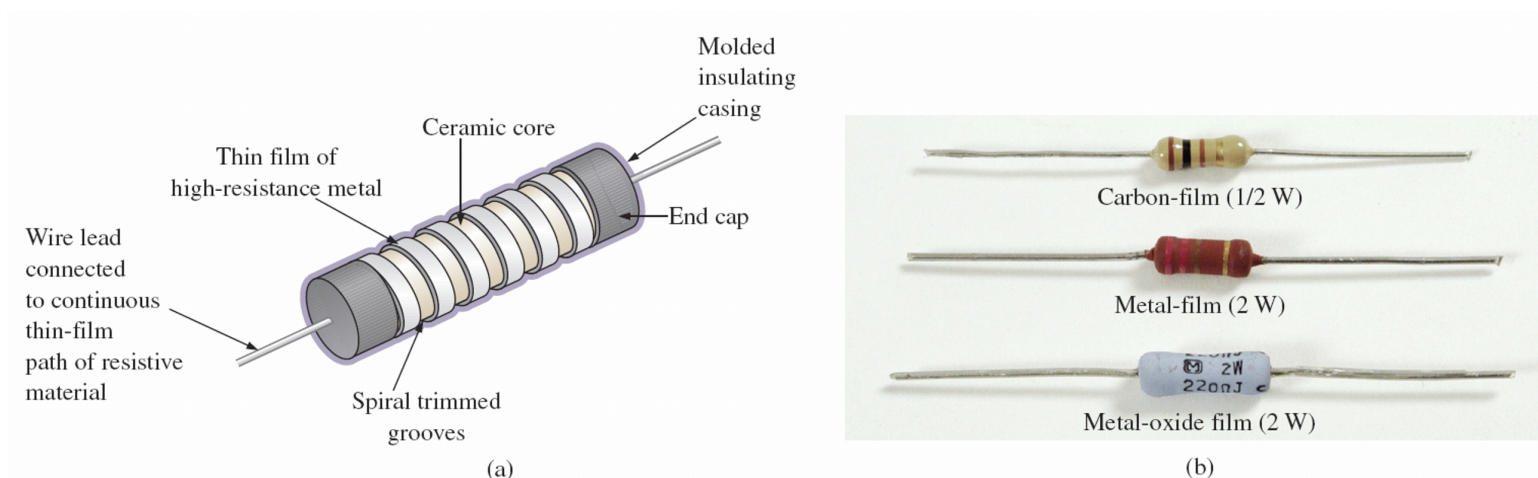


FIG. 3.12 *Film resistors: (a) construction; (b) types.*

TYPES OF RESISTORS

Fixed Resistors

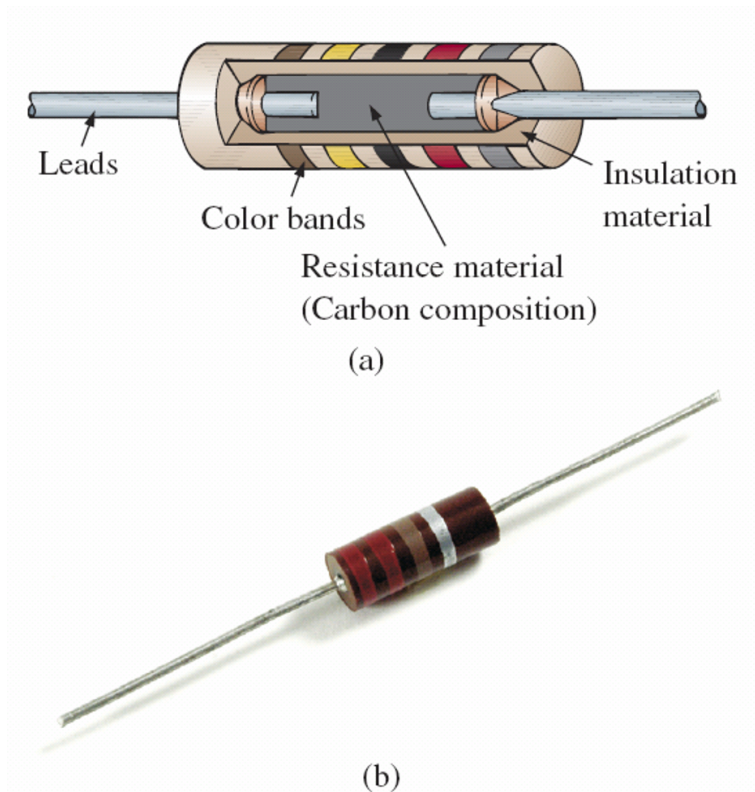


FIG. 3.13 *Fixed-composition resistors: (a) construction; (b) appearance.*

TYPES OF RESISTORS

Fixed Resistors

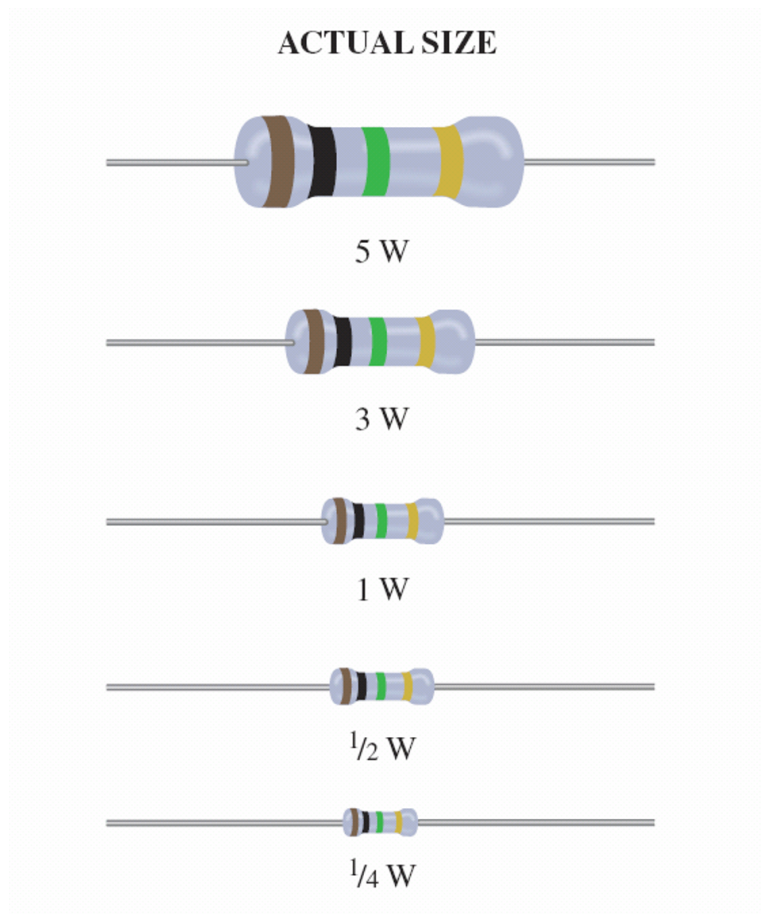


FIG. 3.14 *Fixed metal-oxide resistors of different wattage ratings.*

TYPES OF RESISTORS

Fixed Resistors

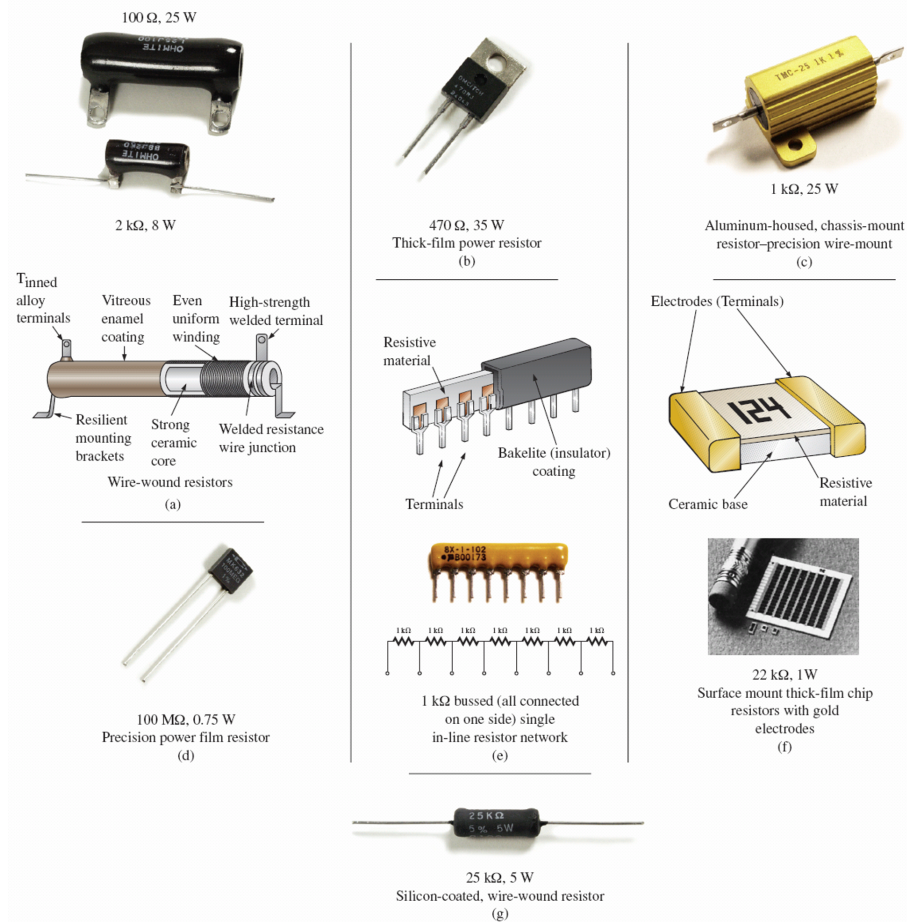


FIG. 3.15 *Various types of fixed resistors.*

TYPES OF RESISTORS

Maximum Voltage Rating

- Every resistor has a maximum voltage rating
 - Both must be considered with the use of any resistor in any application
- In some cases the maximum voltage rating may seem so high from typical operating voltages that the power rating is the only one of any consequence

TYPES OF RESISTORS

Variable Resistors

- Variable resistors, as the name implies, have a terminal resistance that can be varied by turning a dial, knob, screw, or whatever seems appropriate for the application.
- They can have two or three terminals, but most have three terminals. If the two- or three-terminal device is used as a variable resistor, it is usually referred to as a rheostat.

TYPES OF RESISTORS

Variable Resistors

- If the three-terminal device is used for controlling potential levels, it is then commonly called a potentiometer.
- Even though a three-terminal device can be used as a rheostat or a potentiometer (depending on how it is connected), it is typically called a potentiometer when listed in trade magazines or requested for a particular application.

TYPES OF RESISTORS

Variable Resistors

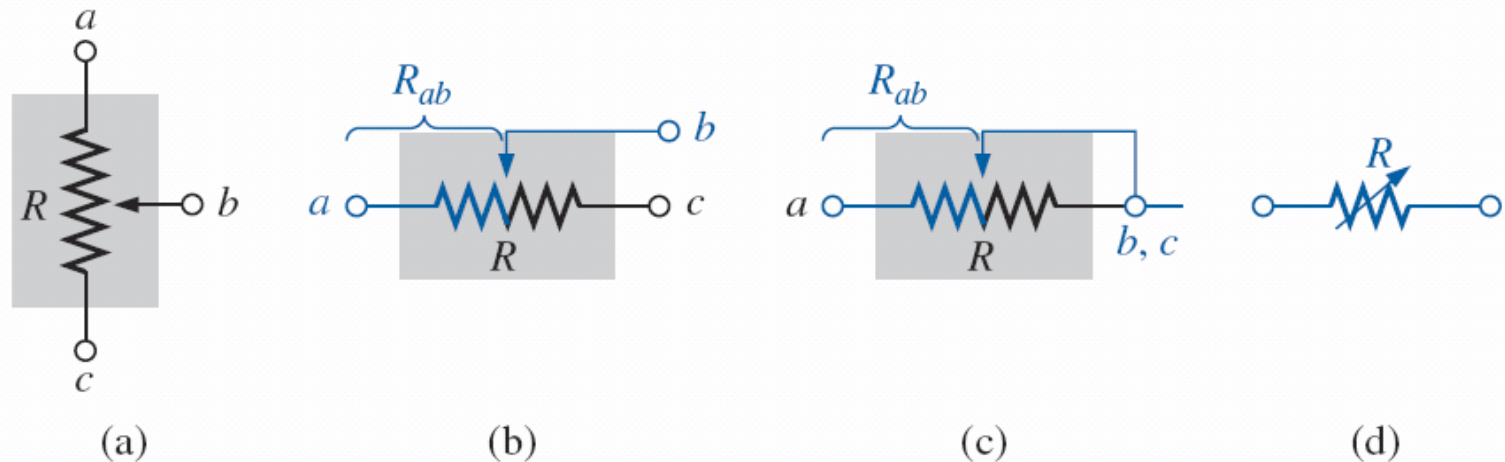


FIG. 3.16 *Potentiometer: (a) symbol; (b) and (c) rheostat connections; (d) rheostat symbol.*

TYPES OF RESISTORS

Variable Resistors

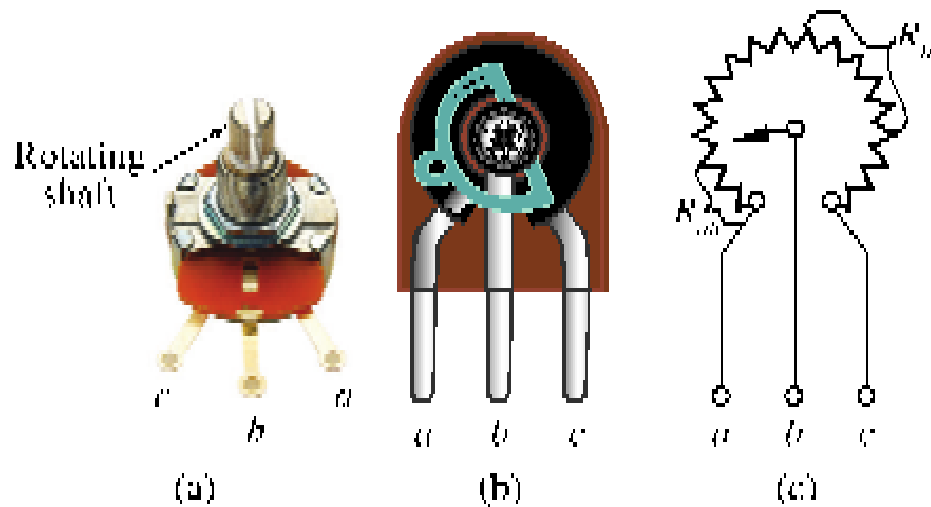


FIG. 3.17 *Molded composition-type potentiometer.*
(Courtesy of Allen-Bradley Co.)

TYPES OF RESISTORS

Variable Resistors

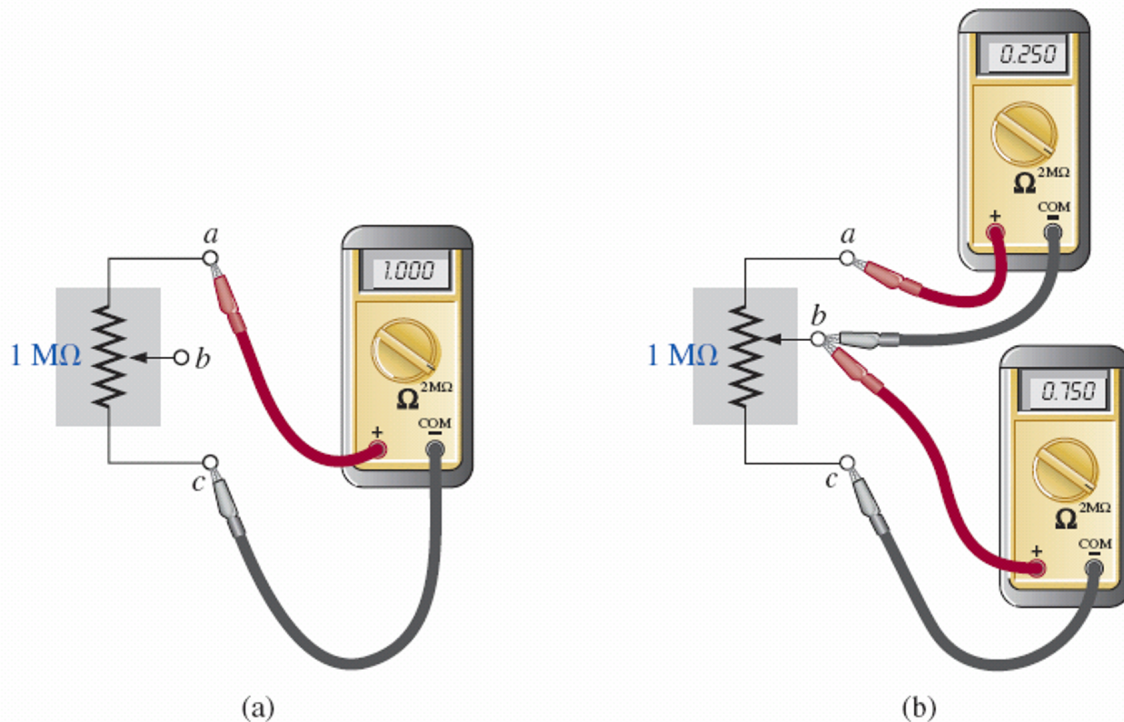
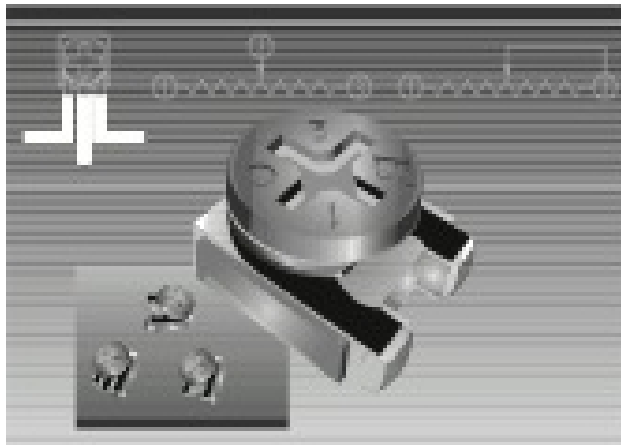


FIG. 3.18 Resistance components of a potentiometer: (a) between outside terminals; (b) between wiper arm and each outside terminal.

TYPES OF RESISTORS

Variable Resistors



(a)



(b)



(c)

FIG. 3.19 Variable resistors: (a) 4 mm (5/32 in.) trimmer (courtesy of Bourns, Inc.); (b) conductive plastic and cermet elements (courtesy of Honeywell Clarostat); (c) three-point wire-wound resistor.

TYPES OF RESISTORS

Variable Resistors

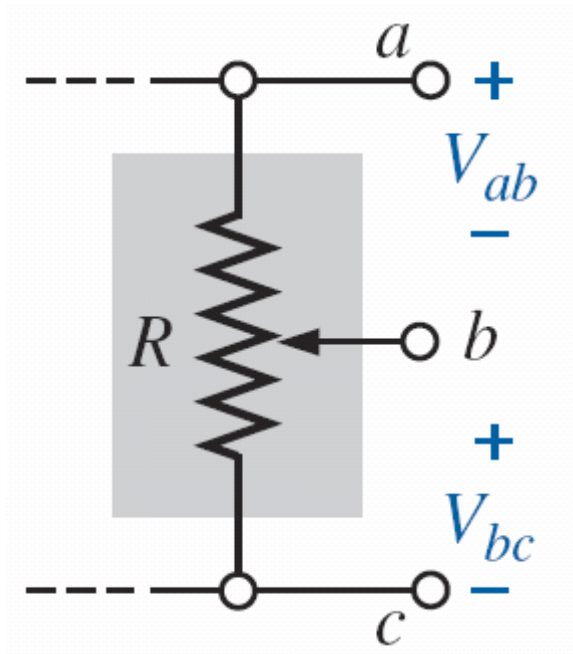


FIG. 3.20
*Potentiometer
control of voltage
levels.*

COLOR CODING AND STANDARD RESISTOR VALUES

- A wide variety of resistors, fixed or variable, are large enough to have their resistance in ohms printed on the casing.
- Some, however, are too small to have numbers printed on them, so a system of color coding is used.
- For the thin-film resistor, four, five, or six bands may be used.

COLOR CODING AND STANDARD RESISTOR VALUES

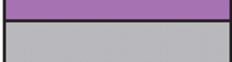
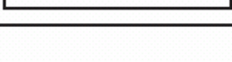
- The four-band scheme is described.
- Later in this section the purpose of the fifth and sixth bands will be described.

COLOR CODING AND STANDARD RESISTOR VALUES



FIG. 3.21 *Color coding for fixed resistors.*

COLOR CODING AND STANDARD RESISTOR VALUES

Number		Color
0		Black
1		Brown
2		Red
3		Orange
4		Yellow
5		Green
6		Blue
7		Violet
8		Gray
9		White

$\pm 5\%$ (0.1 multiplier if 3rd band)		Gold
$\pm 10\%$ (0.01 multiplier if 3rd band)		Silver

FIG. 3.22
Color coding.

COLOR CODING AND STANDARD RESISTOR VALUES



FIG. 3.23
Example 3.11.



FIG. 3.24
Example 3.12.

COLOR CODING AND STANDARD RESISTOR VALUES

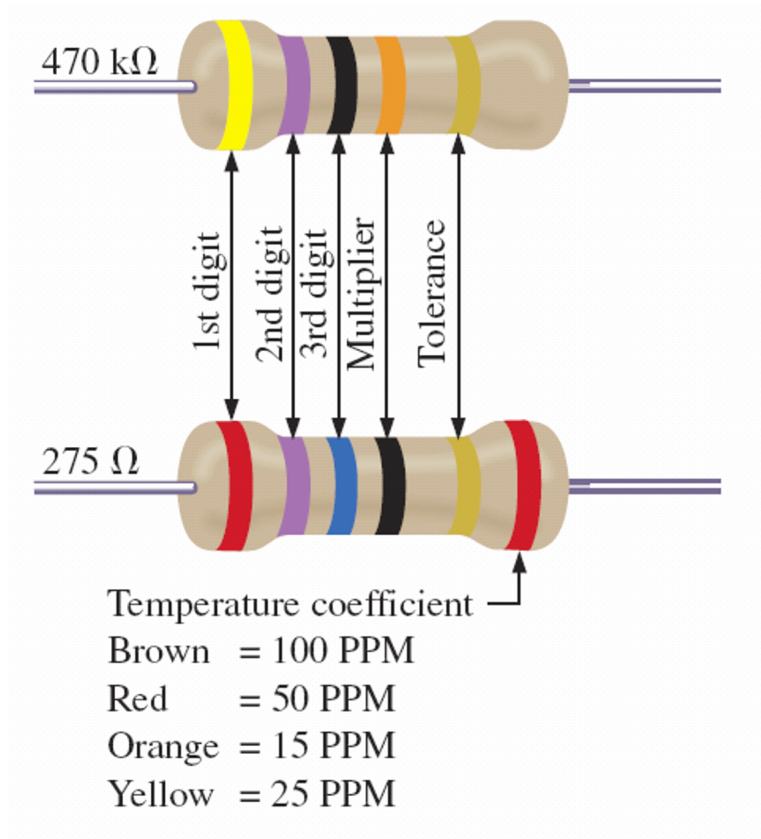


FIG. 3.25 *Five-band color coding for fixed resistors.*

COLOR CODING AND STANDARD RESISTOR VALUES

Ohms (Ω)					Kilohms ($k\Omega$)		Megohms ($M\Omega$)	
0.10	1.0	10	100	1000	10	100	1.0	10.0
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	1.2	12	120	1200	12	120	1.2	12.0
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	1.5	15	150	1500	15	150	1.5	15.0
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	1.8	18	180	1800	18	180	1.8	18.0
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	2.2	22	220	2200	22	220	2.2	22.0
0.24	2.4	24	240	2400	24	240	2.4	
0.27	2.7	27	270	2700	27	270	2.7	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	3.3	33	330	3300	33	330	3.3	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	3.9	39	390	3900	39	390	3.9	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	4.7	47	470	4700	47	470	4.7	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	5.6	56	560	5600	56	560	5.6	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	6.8	68	680	6800	68	680	6.8	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	8.2	82	820	8200	82	820	8.2	
0.91	9.1	91	910	9100	91	910	9.1	

TABLE 3.5
*Standard values of
commercially
available resistors.*

COLOR CODING AND STANDARD RESISTOR VALUES

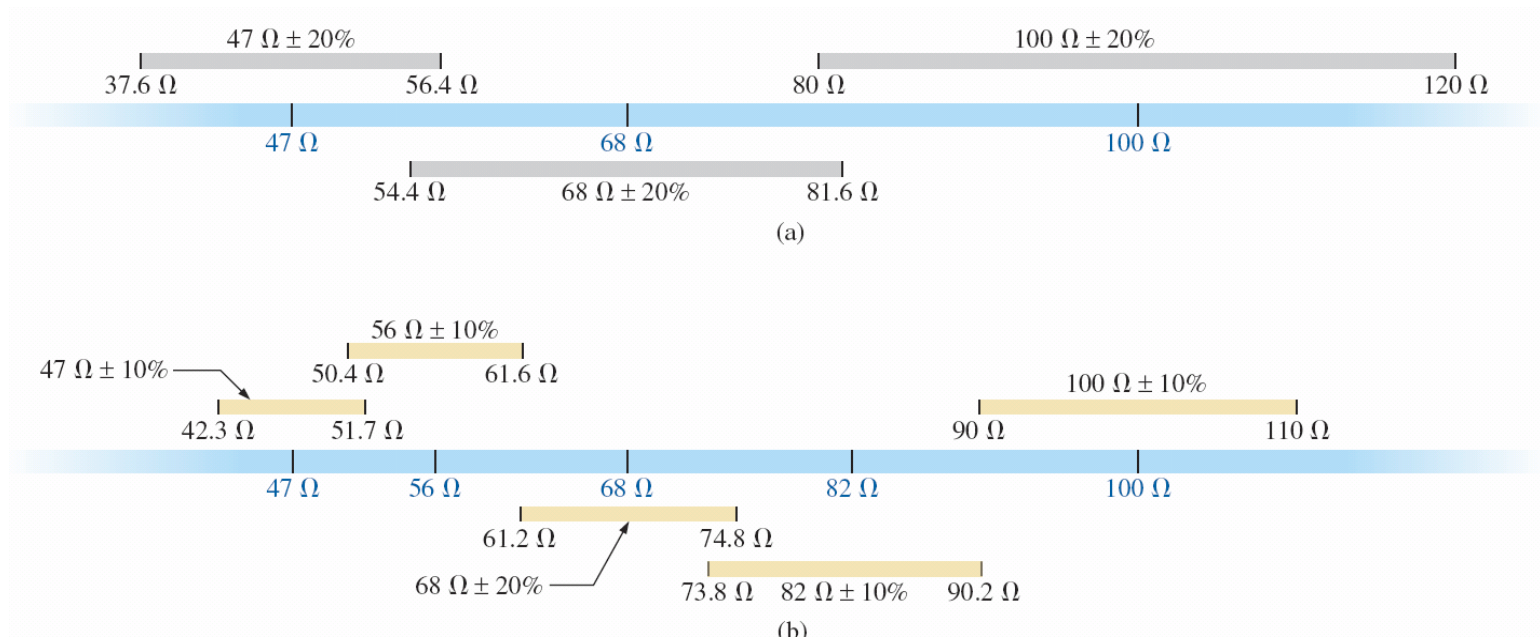


FIG. 3.26 *Guaranteeing the full range of resistor values for the given tolerance: (a) 20%; (b) 10%.*

COLOR CODING AND STANDARD RESISTOR VALUES

- Surface Mount Resistors
 - In general, surface mount resistors are marked in three ways: color coding, three symbols, and two symbols.
 - The color coding is the same as just described earlier in this section for through-hole resistors.
 - The three-symbol approach uses three digits. The first two define the first two digits of the value; the last digit defines the power of the power-of-ten multiplier.

CONDUCTANCE

- By finding the reciprocal of the resistance of a material, we have a measure of how well the material conducts electricity.
- The quantity is called conductance, has the symbol G , and is measured in siemens.

OHMMETERS

- The ohmmeter is an instrument used to perform the following tasks and several other useful functions:
 - Measure the resistance of individual or combined elements.
 - Detect open-circuit (high-resistance) and short-circuit (lowresistance) situations.

OHMMETERS

- Check the continuity of network connections and identify wires of a multilead cable.
- Test some semiconductor (electronic) devices.

OHMMETERS

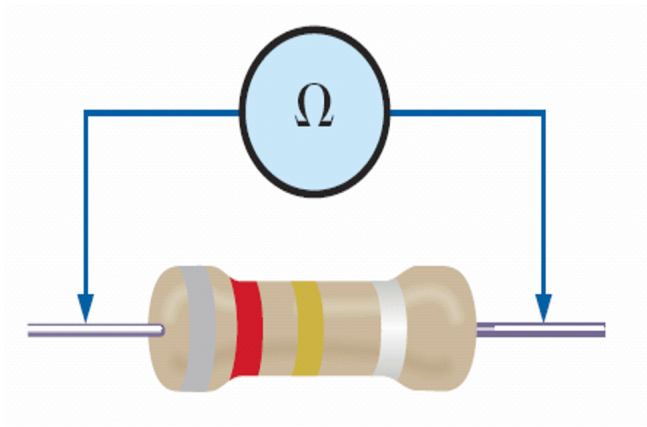


FIG. 3.28
Measuring the resistance of a single element.

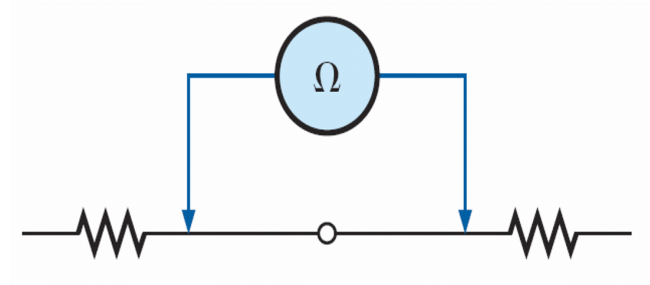


FIG. 3.29
Checking the continuity of a connection.

OHMMETERS

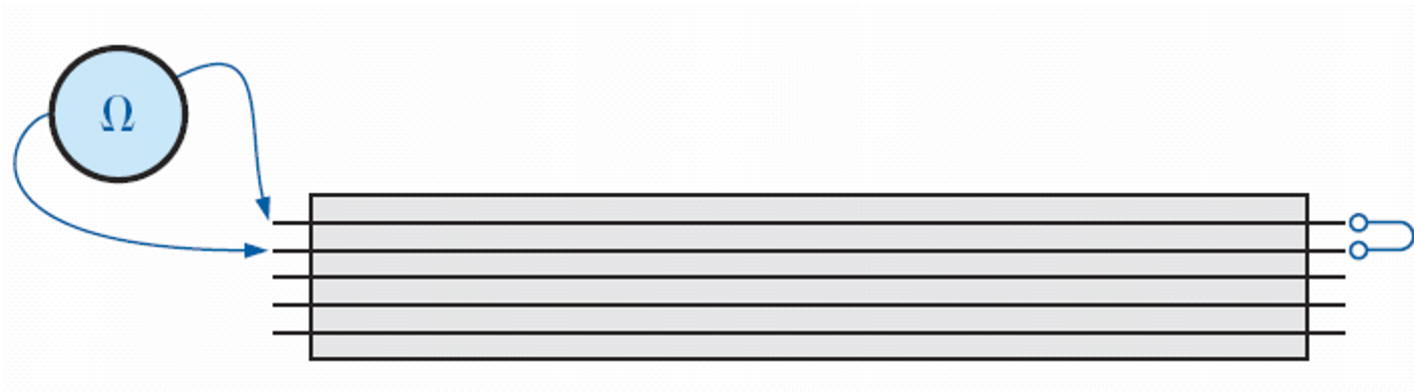


FIG. 3.30 *Identifying the leads of a multilead cable.*

RESISTANCE: METRIC UNITS

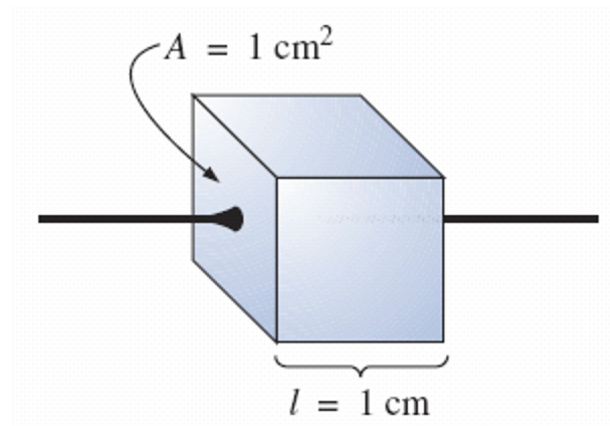


FIGURE 3.31 *Defining r in ohm-centimeters.*

RESISTANCE: METRIC UNITS

Material	$\Omega\text{-cm}$
Silver	1.645×10^{-6}
Copper	1.723×10^{-6}
Gold	2.443×10^{-6}
Aluminum	2.825×10^{-6}
Tungsten	5.485×10^{-6}
Nickel	7.811×10^{-6}
Iron	12.299×10^{-6}
Tantalum	15.54×10^{-6}
Nichrome	99.72×10^{-6}
Tin oxide	250×10^{-6}
Carbon	3500×10^{-6}

TABLE 3.6 *Resistivity (r) of various materials.*

RESISTANCE: METRIC UNITS

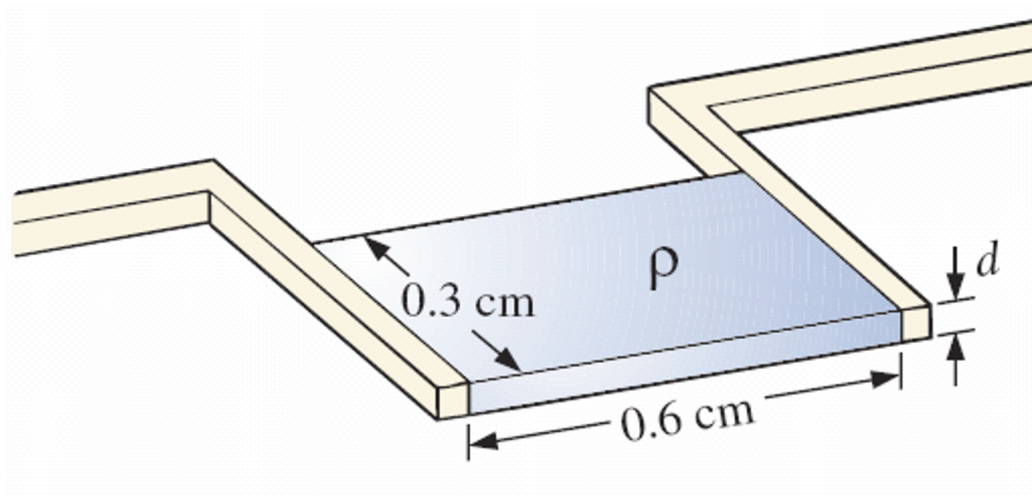


FIG. 3.32 *Thin-film resistor. Example 3.16.*

RESISTANCE: METRIC UNITS

Conductor ($\Omega\text{-cm}$)	Semiconductor ($\Omega\text{-cm}$)	Insulator ($\Omega\text{-cm}$)
Copper 1.723×10^{-6}	Ge 50 Si 200×10^3 GaAs 70×10^6	In general: 10^{15}

TABLE 3.7 *Comparing levels of r in $\Omega\text{-cm}$.*

THE FOURTH ELEMENT—THE MEMRISTOR

- In May 2008 researchers at Hewlett Packard Laboratories led by Dr. Stanley Williams had an amazing announcement—the discovery of the “missing” link in basic electronic circuit theory called a memristor.

THE FOURTH ELEMENT—THE MEMRISTOR

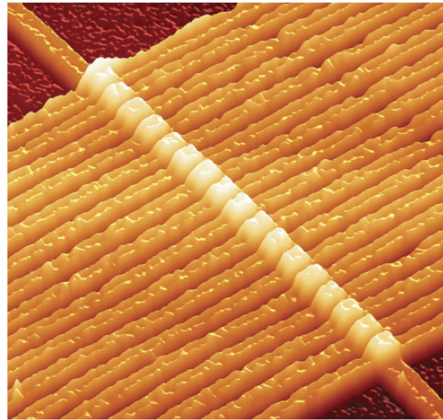


FIG. 3.33 (a) An image of a circuit with 17 memristors captured by an atomic force microscope. Each memristor is composed of two layers of titanium dioxide sandwiched between a lower common wire and its own upper wire. As a voltage is applied across a memristor, the small signal resistance of one of the titanium dioxide layers is changed, which in turn is used as a method to register data. (b) symbol. [(a) Courtesy of J. Joshua Yang and R. Stanley Williams, HP Labs.]

THE FOURTH ELEMENT—THE MEMRISTOR

- The four basic circuit quantities of charge, current, voltage, and magnetic flux can be related in six ways.
- Three relations derive from the basic elements of the resistor, the capacitor, and the inductor.

THE FOURTH ELEMENT—THE MEMRISTOR

- The resistor provides a direct relationship between current and voltage, the capacitor provides a relationship between charge and voltage, and the inductor provides a relationship between current and magnetic flux.
- That leaves the relationship between the magnetic field and the charge moving through an element.

THE FOURTH ELEMENT—THE MEMRISTOR

- The memristor is a device whose resistance increases with increase in the flow of charge in one direction and decreases as the flow of charge decreases in the reverse direction.
- Furthermore, and vastly important, it maintains its new resistance level when the excitation has been removed.

SUPERCONDUCTORS

- The field of electricity/electronics is one of the most exciting of our time.
- New developments appear almost weekly from extensive research and development activities.

SUPERCONDUCTORS

- The research drive to develop a superconductor capable of operating at temperatures closer to room temperature has been receiving increasing attention in recent years due to the need to cut energy losses.
 - What are superconductors?
 - Why is their development so important?

SUPERCONDUCTORS

- In a nutshell, superconductors are conductors of electric charge that, for all practical purposes, have zero resistance.

SUPERCONDUCTORS

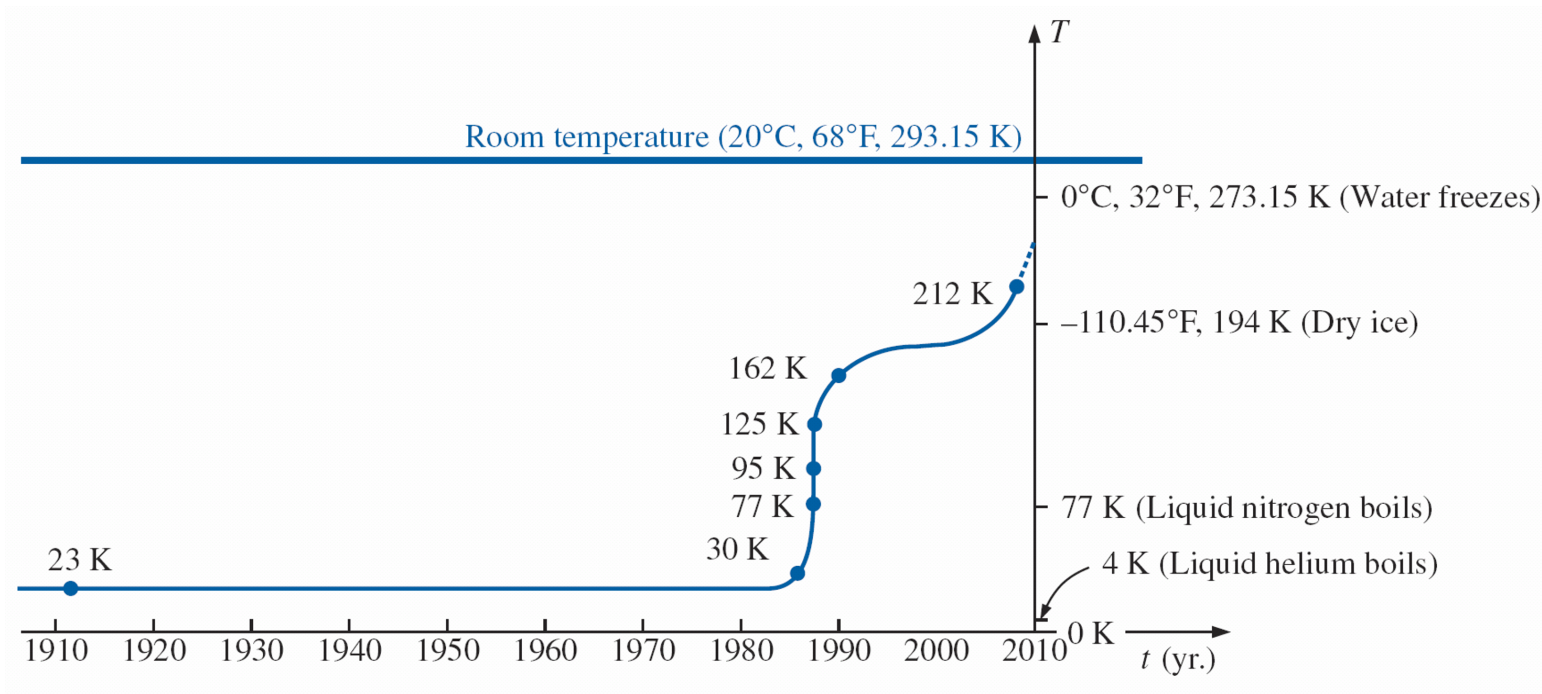


FIG. 3.34 *Rising temperatures of superconductors.*

SUPERCONDUCTORS

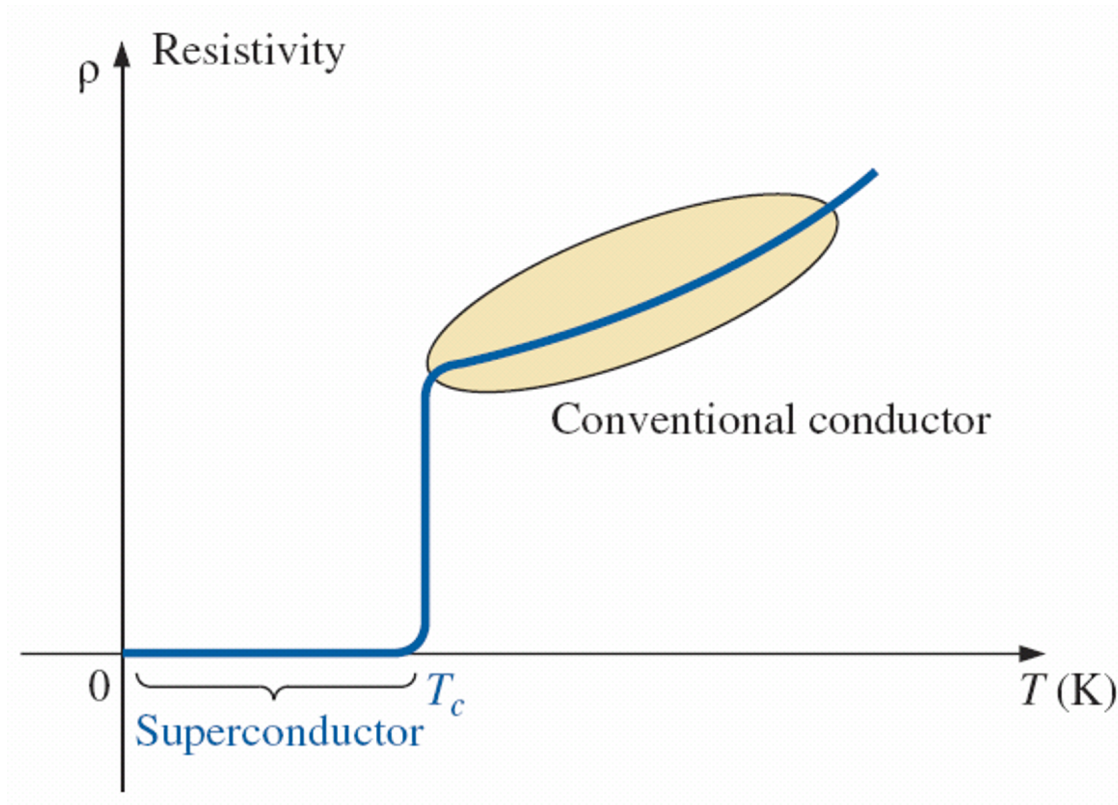


FIG. 3.35 *Defining the critical temperature T_c .*

THERMISTORS

- The thermistor is a two-terminal semiconductor device whose resistance, as the name suggests, is temperature sensitive.

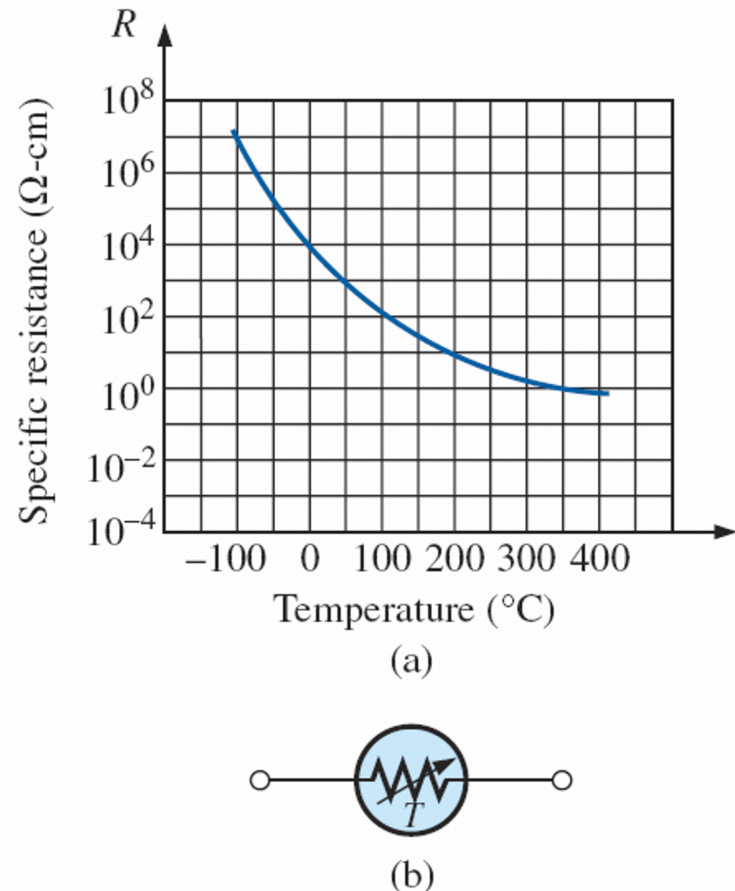


FIG. 3.36 Thermistor: (a) characteristics; (b) symbol.

THERMISTORS

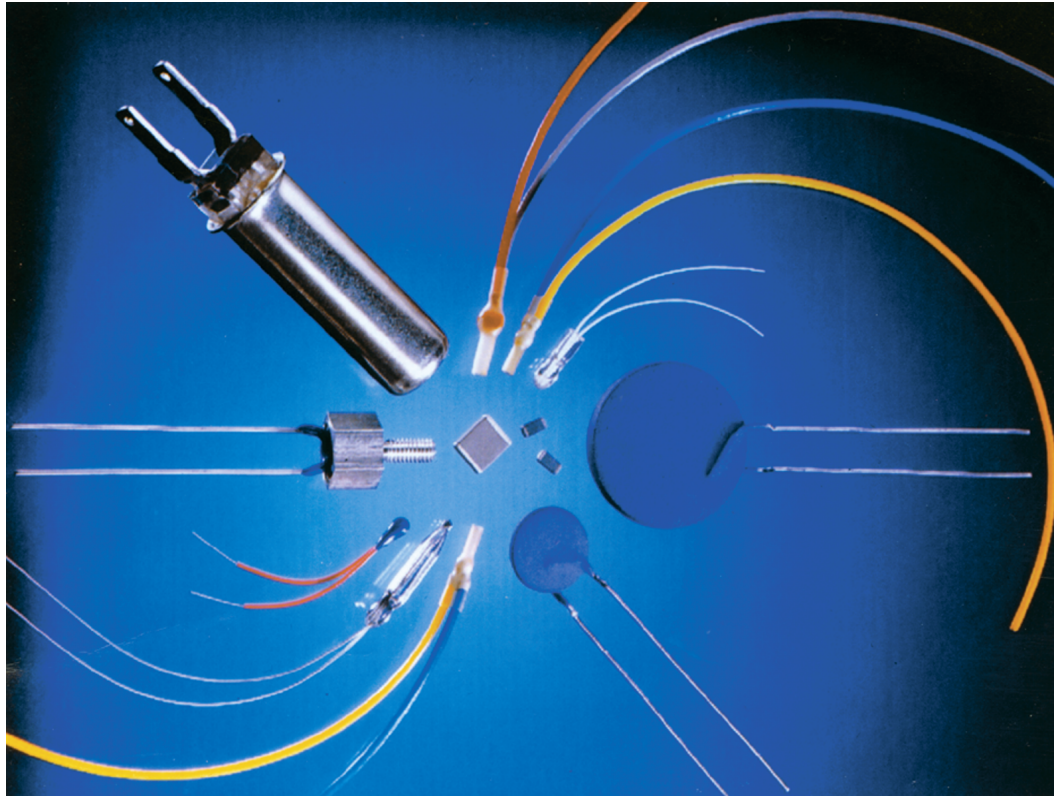
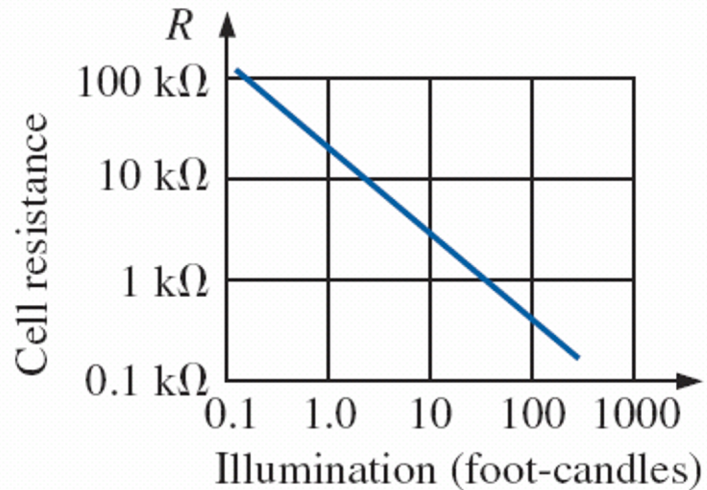
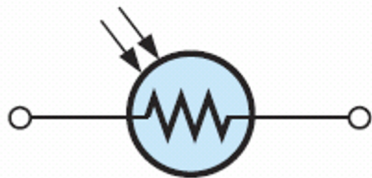


FIG. 3.37 *NTC (negative temperature coefficient) and PTC (positive temperature coefficient) thermistors.*

THERMISTORS



(a)



(b)

FIG. 3.38

*Photoconductive cell:
(a) characteristics. (b)
symbol.*

PHOTOCONDUCTIVE CELL

- The photoconductive cell is a two-terminal semiconductor device whose terminal resistance is determined by the intensity of the incident light on its exposed surface.

PHOTOCONDUCTIVE CELL

- As the applied illumination increases in intensity, the energy state of the surface electrons and atoms increases, with a resultant increase in the number of “free carriers” and a corresponding drop in resistance.

PHOTOCONDUCTIVE CELL

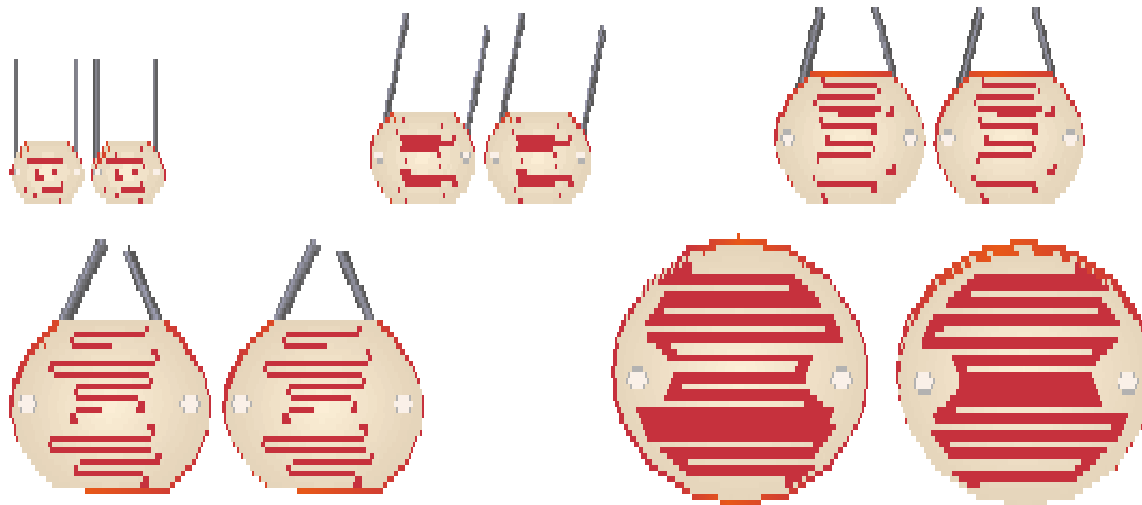
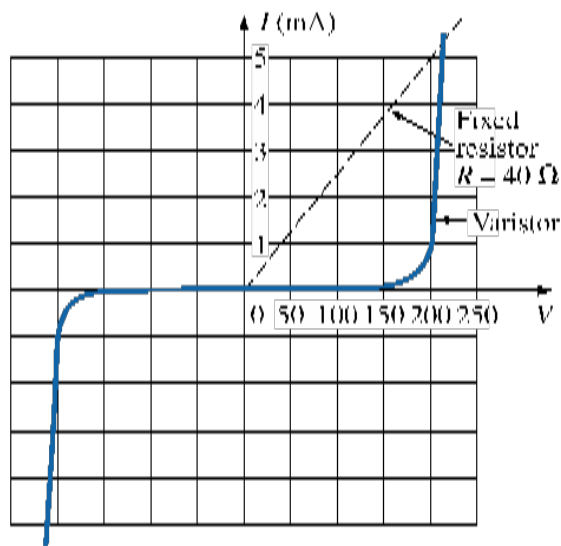


FIG. 3.39
Photoconductive cells.

VARISTORS

- Varistors are voltage-dependent, nonlinear resistors used to suppress high-voltage transients; that is, their characteristics enable them to limit the voltage that can appear across the terminals of a sensitive device or system.

VARISTORS



(a)



(b)

FIG. 3.40 Varistors available with maximum dc voltage ratings between 18 V and 615 V.

APPLICATIONS

- The following are examples of how resistance can be used to perform a variety of tasks, from heating to measuring the stress or strain on a supporting member of a structure.
- In general, resistance is a component of every electrical or electronic application.

APPLICATIONS: Electric Baseboard Heating Element

- One of the most common applications of resistance is in household fixtures such as toasters and baseboard heating where the heat generated by current passing through a resistive element is employed to perform a useful function.

APPLICATIONS: Electric Baseboard Heating Element

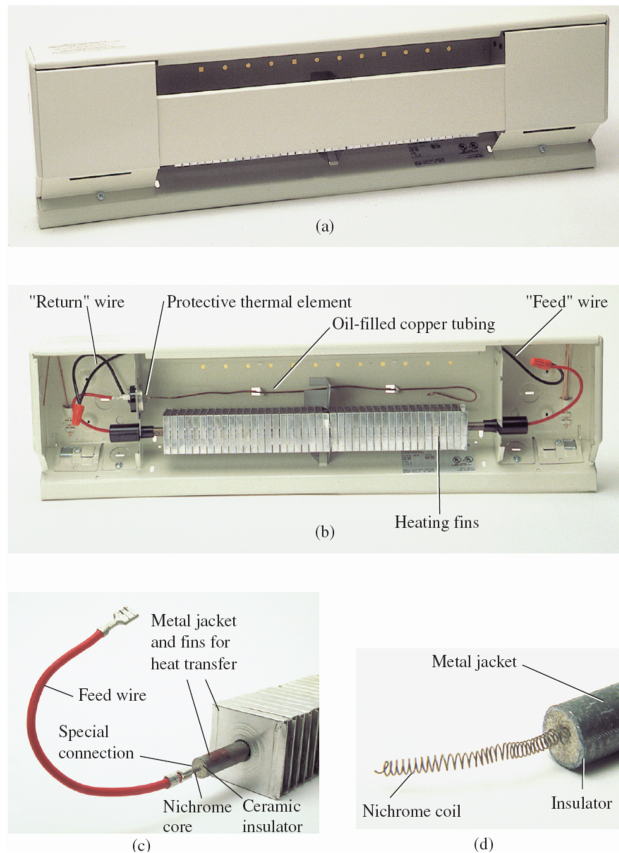


FIG. 3.41 *Electric baseboard: (a) 2-ft section; (b) interior; (c) heating element; (d) nichrome coil.*

APPLICATIONS

Dimmer Control in an Automobile

- A two-point rheostat is the primary element in the control of the light intensity on the dashboard and accessories of a car.

APPLICATIONS

Dimmer Control in an Automobile

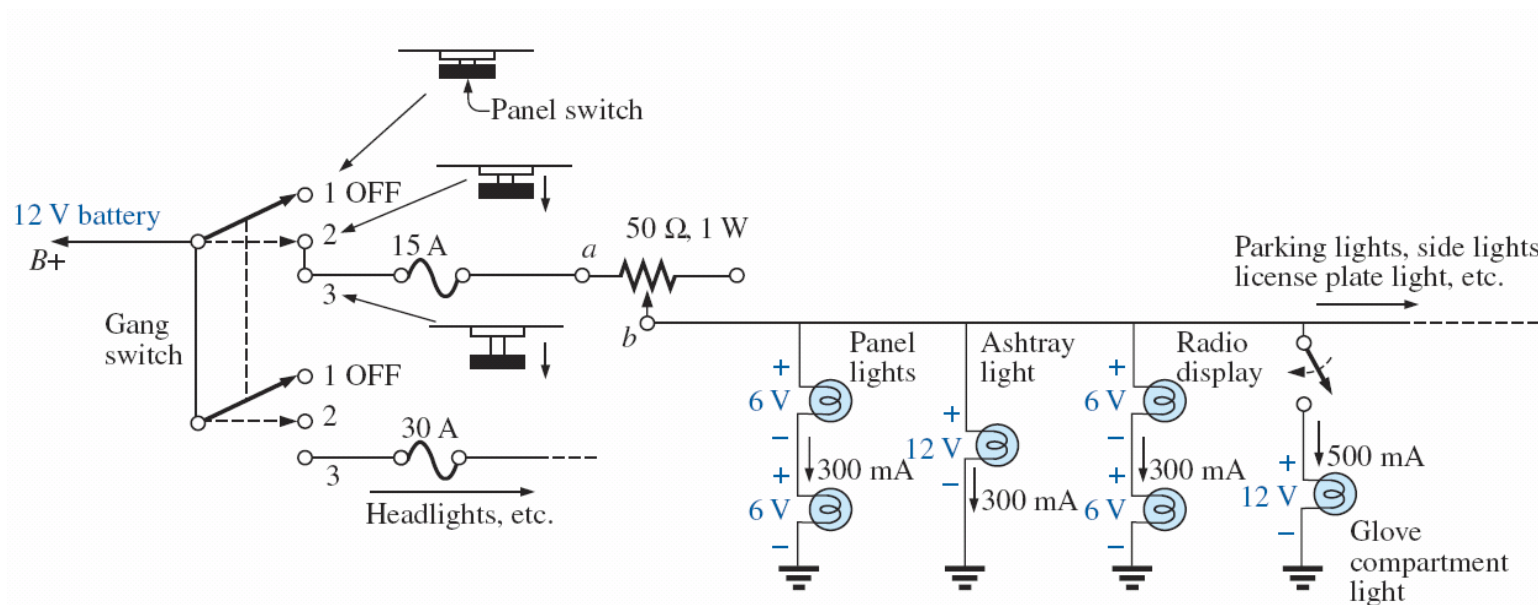


FIG. 3.42 *Dashboard dimmer control in an automobile.*

APPLICATIONS

Strain Gauges

- Any change in the shape of a structure can be detected using strain gauges whose resistance changes with applied stress or flex.

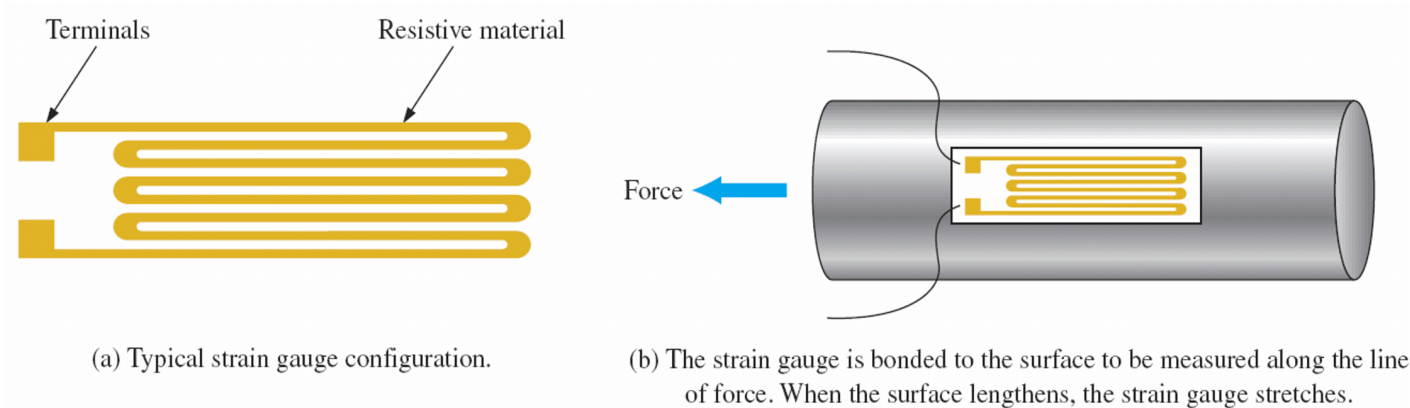
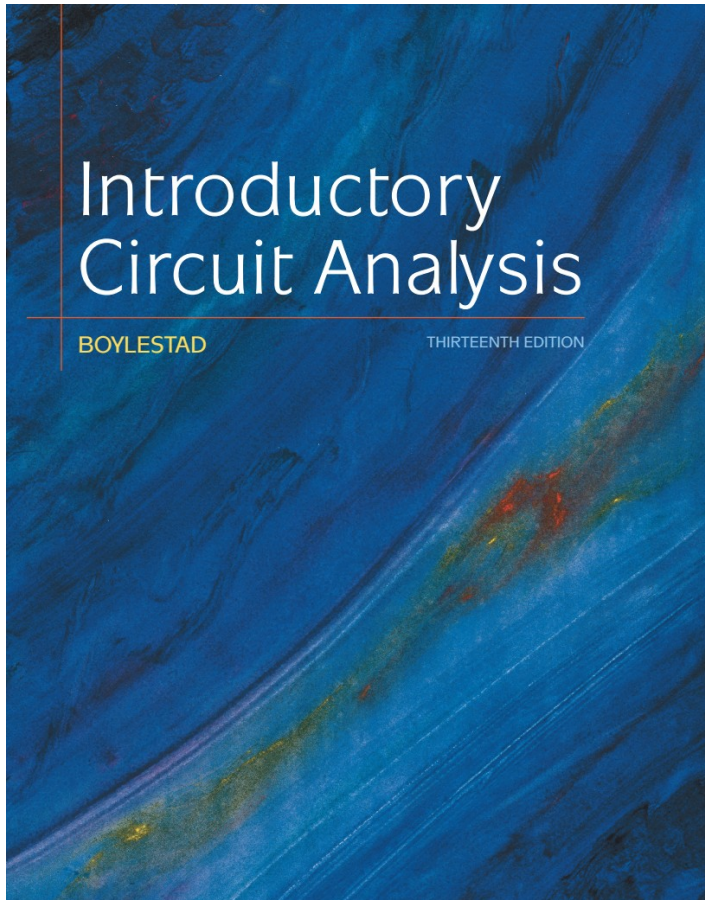


FIG. 3.43 *Resistive strain gauge.*

Introductory Circuit Analysis



CHAPTER 4

Ohm's Law, Power, and Energy

OBJECTIVES

- Understand the importance of Ohm's law and how to apply it to a variety of situations.
- Be able to plot Ohm's law and understand how to "read" a graphical plot of voltage versus current.
- Become aware of the differences between power and energy levels and how to solve for each.

OBJECTIVES

- Understand the power and energy flow of a system, including how the flow affects the efficiency of operation.
- Become aware of the operation of a variety of fuses and circuit breakers and where each is employed.

OHM'S LAW

- The first equation to be described is without question one of the most important to be learned in this field.
- It is applicable to dc circuits, ac circuits, digital and microwave circuits, and, in fact, any type of applied signal.
- In addition, it can be applied over a period of time or for instantaneous responses.

OHM'S LAW

- The equation can be derived directly from the following basic equation for all physical systems:
- Every conversion of energy from one form to another can be related to this equation.
- In electric circuits, the effect we are trying to establish is the flow of charge, or current.

OHM'S LAW

- The potential difference, or voltage, between two points is the cause (“pressure”), and the opposition is the resistance encountered.
- In summary, therefore, the absence of an applied “pressure” such as voltage in an electric circuit will result in no reaction in the system and no current in the electric circuit.

OHM'S LAW

- Current is a reaction to the applied voltage and not the factor that gets the system in motion.
- To continue with the analogy, the greater the pressure at the spigot, the greater is the rate of water flow through the hose, just as applying a higher voltage to the same circuit results in a higher current.

OHM'S LAW

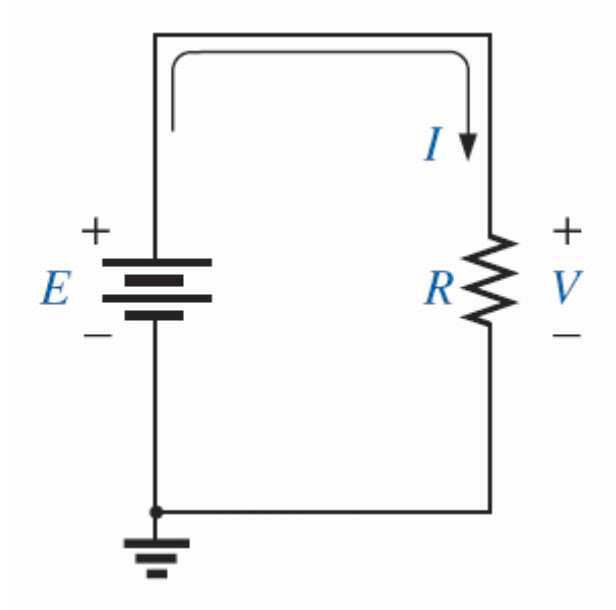


FIG. 4.2
Basic circuit.

OHM'S LAW

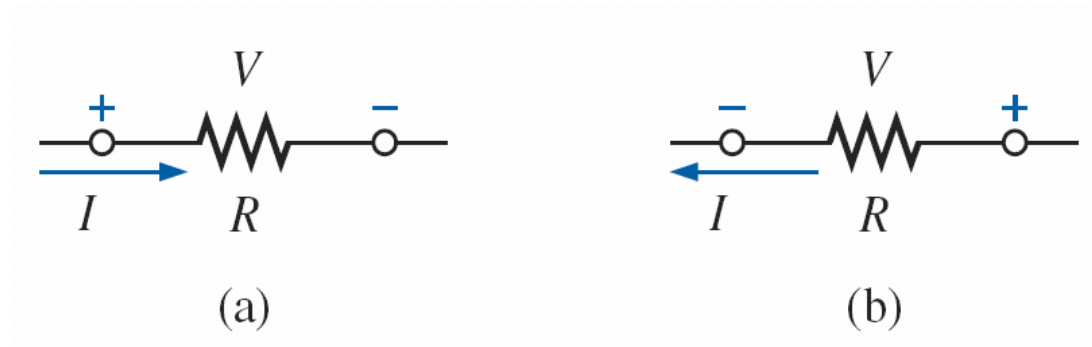


FIG. 4.3
*Defining
polarities.*

OHM'S LAW

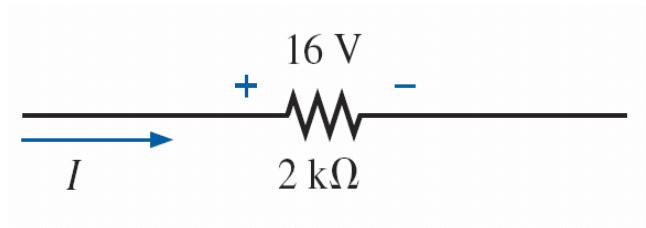


FIG. 4.4
Example
4.3.

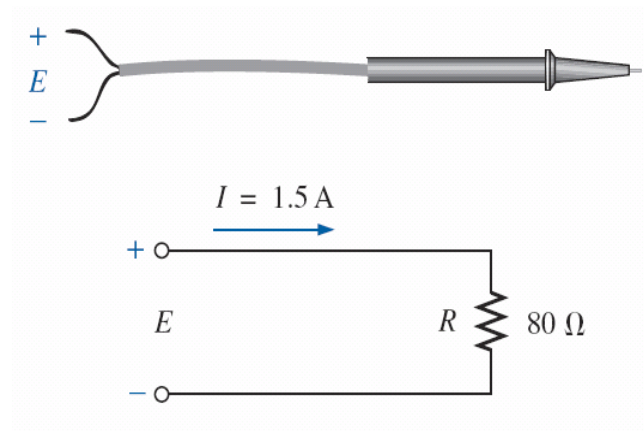


FIG. 4.5
Example
4.4.

PLOTTING OHM'S LAW

- Graphs, characteristics, plots, and the like play an important role in every technical field as modes through which the broad picture of the behavior or response of a system can be conveniently displayed.
- It is therefore critical to develop the skills necessary both to read data and to plot them in such a manner that they can be interpreted easily.

PLOTTING OHM'S LAW

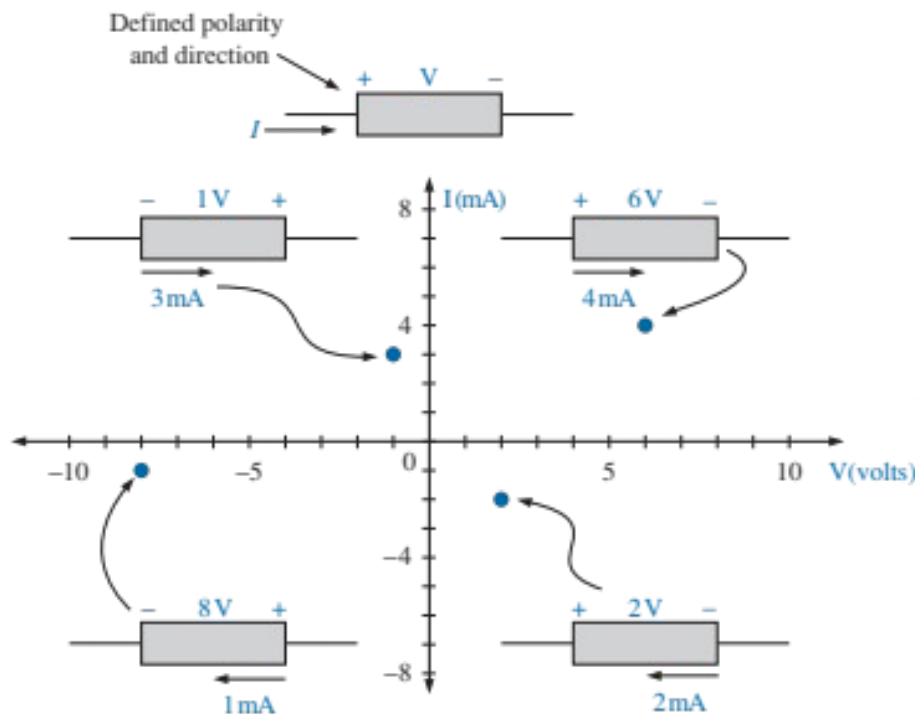


FIG. 4.6

Demonstrating the impact of defined voltage and current on a plot point.

PLOTTING OHM'S LAW

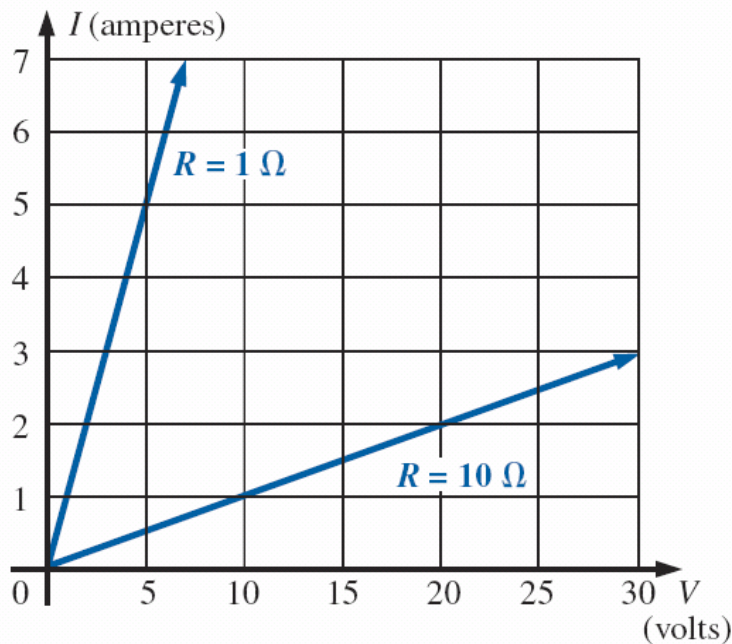


FIG. 4.8

Demonstrating on an I - V plot that the lower the resistance, the steeper is the slope.

PLOTTING OHM'S LAW

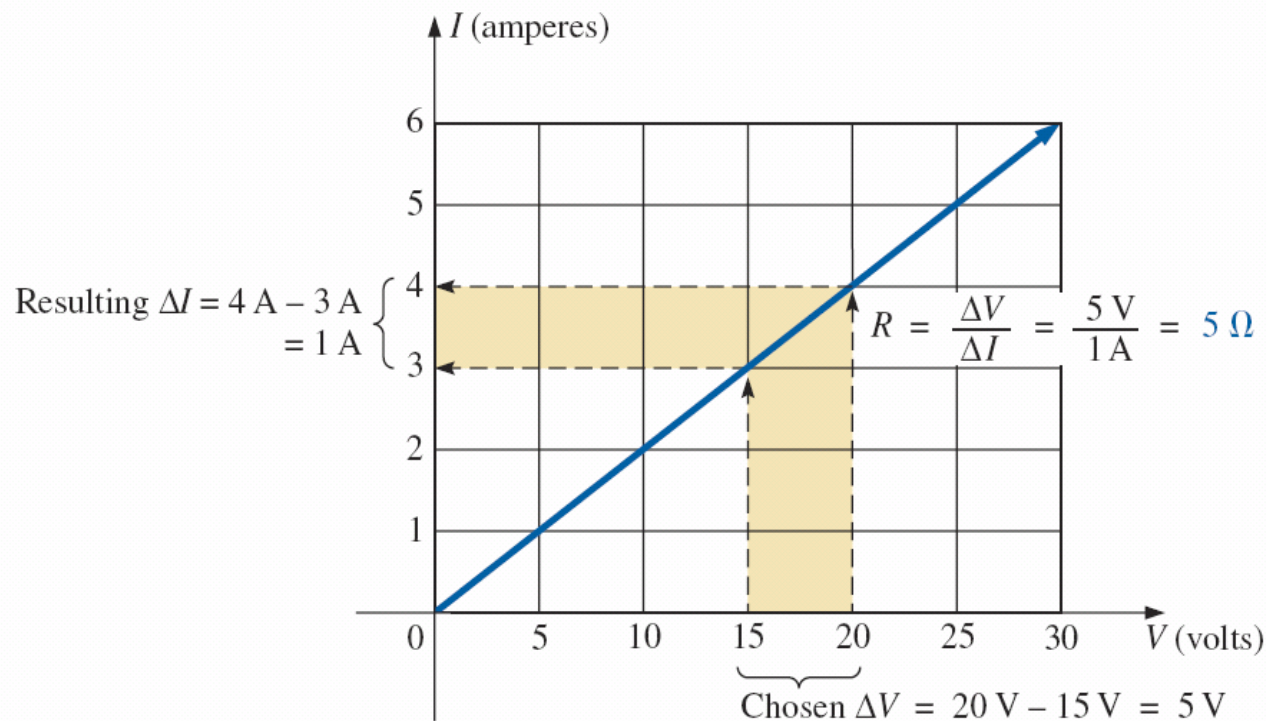


FIG. 4.9
*Applying Eq.
(4.7).*

PLOTTING OHM'S LAW

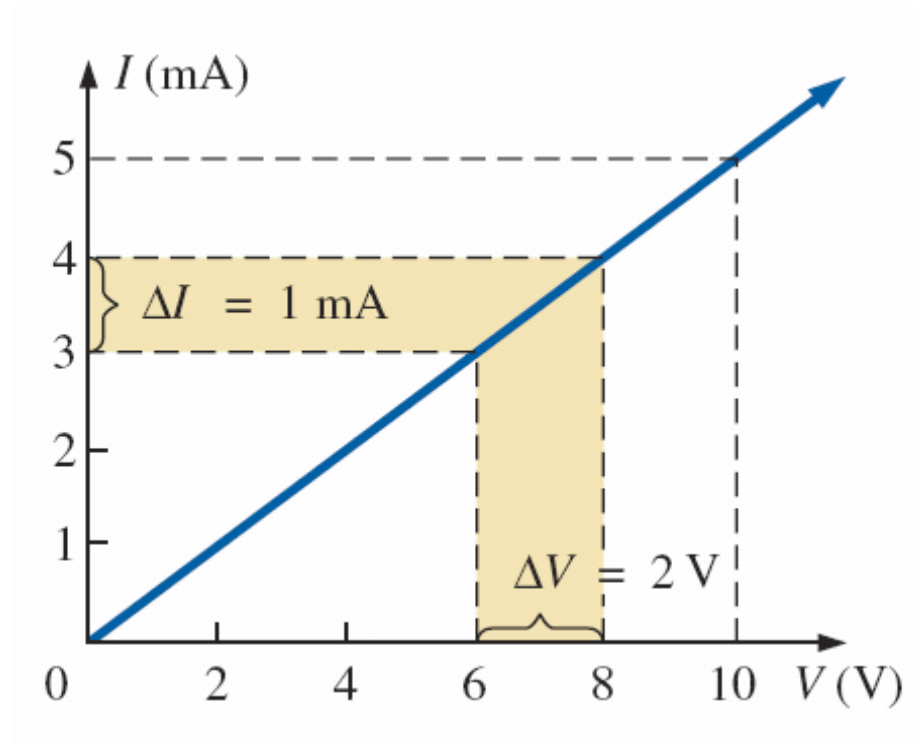


FIG. 4.10

Example 4.5.

PLOTTING OHM'S LAW

- This diode ideally acts as a low-resistance path to current in one direction and a high-resistance path to current in the reverse direction, much like a switch that passes current in only one direction.

PLOTTING OHM'S LAW

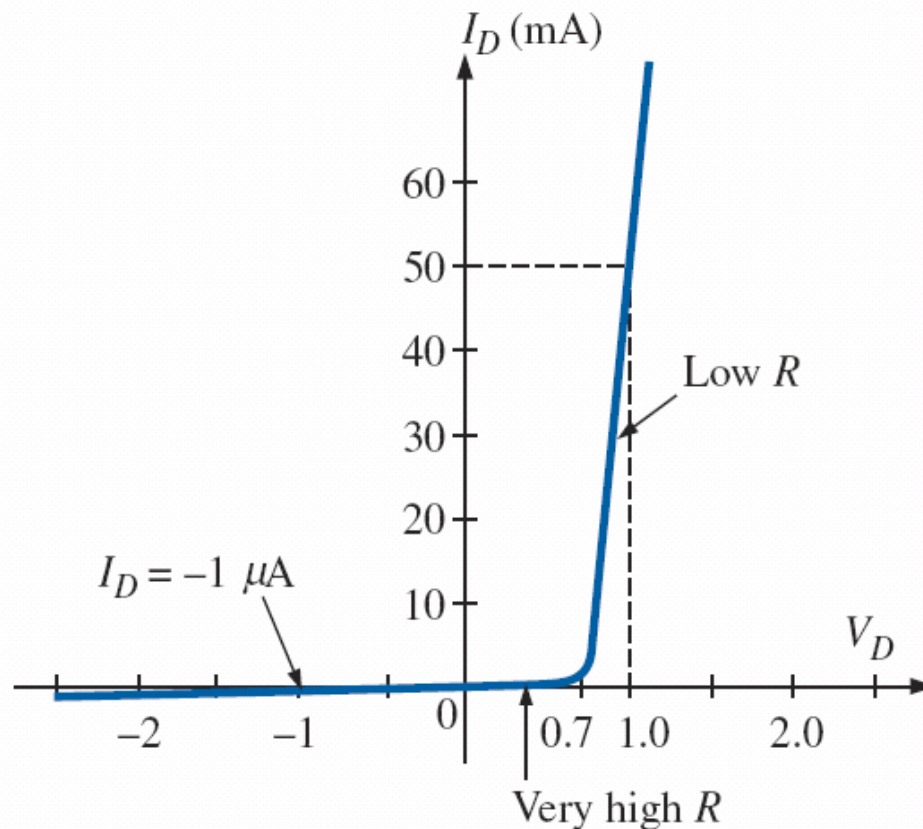


FIG. 4.11 *Semiconductor diode characteristics.*

POWER

- In general, the term power is applied to provide an indication of how much work (energy conversion) can be accomplished in a specified amount of time; that is, power is a rate of doing work.
- Since energy is measured in joules (J) and time in seconds (s), power is measured in joules/second (J/s).

POWER

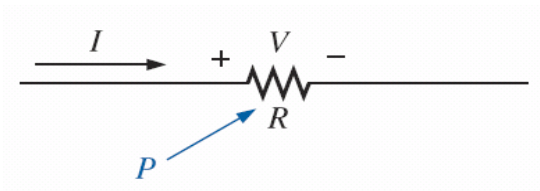


FIG. 4.13 *Defining the power to a resistive element.*

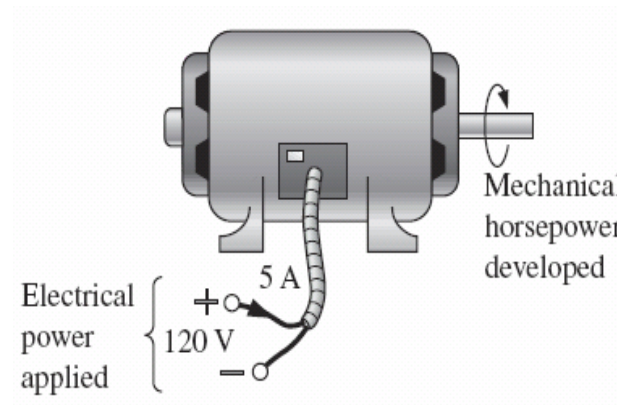


FIG. 4.14
Example 4.6.

POWER

- The power associated with any supply is not simply a function of the supply voltage. It is determined by the product of the supply voltage and its maximum current rating.

POWER

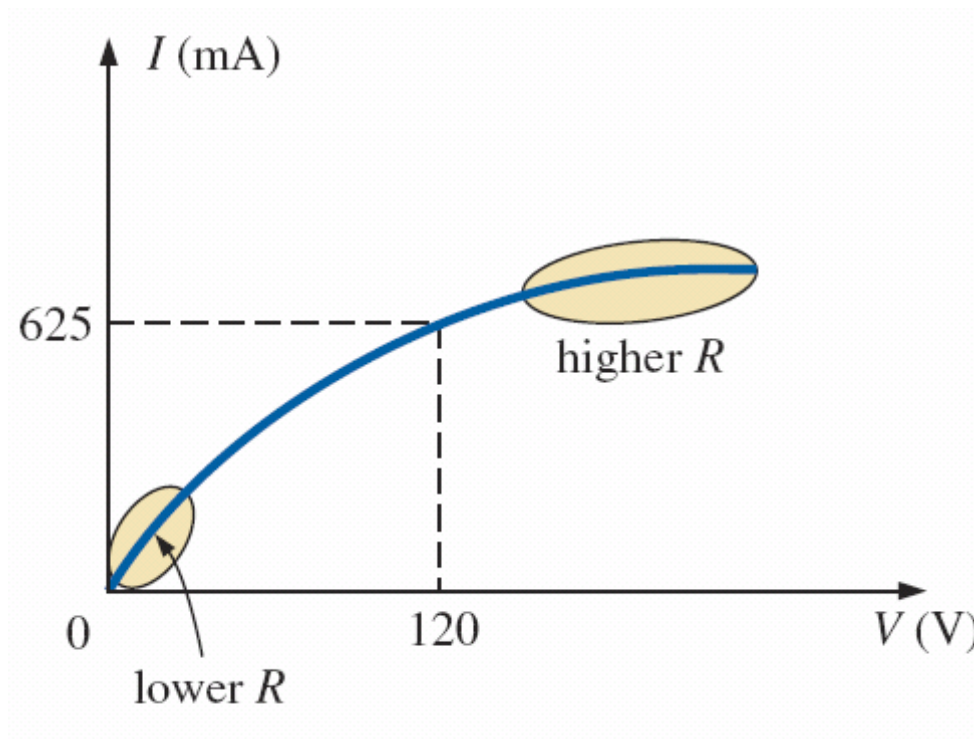


FIG. 4.15 *The nonlinear I - V characteristics of a 75 W light bulb (Example 4.8).*

ENERGY

- To develop some sense for the kilowatthour energy level, consider that 1 kWh is the energy dissipated by a 100 W bulb in 10 h.
- The kilowatthour meter is an instrument for measuring the energy supplied to the residential or commercial user of electricity.

ENERGY



(a)



(b)

FIG. 4.17 *Kilowatt-hour meters: (a) analog; (b) digital.*
(Courtesy of ABB Electric Metering Systems.)

ENERGY

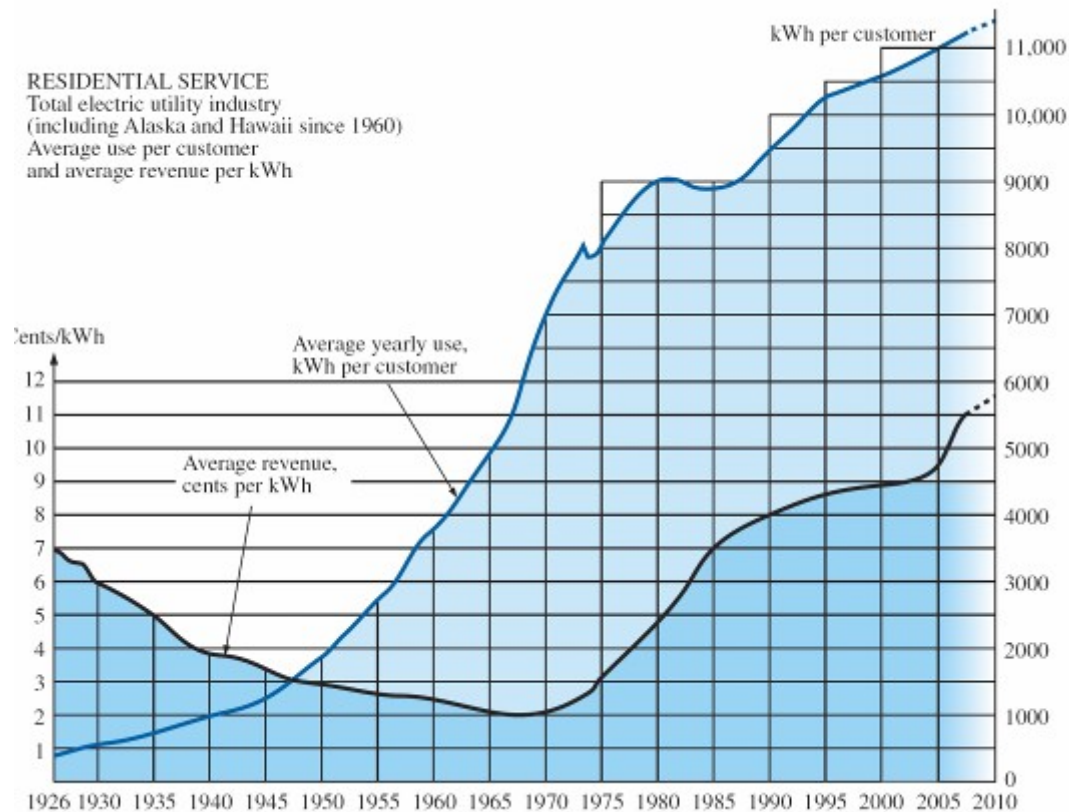


FIG. 4.19 *Cost per kWh and average kWh per customer versus time. (Based on data from Edison Electric Institute.)*

ENERGY

Appliance	Wattage Rating	Appliance	Wattage Rating
Air conditioner (room)	1400	Laptop computer: Sleep	<1 (typically 0.3 to 0.5)
Blow dryer	1300	Average use	78
Cellular phone: Standby	$\cong 35$ mW	Microwave oven	1200
Talk	$\cong 4.3$ W	Nintendo Wii	19
Clock	2	Radio	70
Clothes dryer (electric)	4300	Range (self-cleaning)	12,200
Coffee maker	900	Refrigerator (automatic defrost)	1800
Dishwasher	1200	Shaver	15
Fan: Portable	90	Sun lamp	280
Window	200	Toaster	1200
Heater	1500	Trash compactor	400
Heating equipment: Furnace fan	320	TV: Plasma	340
Oil-burner motor	230	LCD	220
Iron, dry or steam	1000	VCR/DVD	25
		Washing machine	500
		Water heater	4500
		Xbox 360	187

TABLE 4.1 *Typical wattage ratings of some common household items.*

EFFICIENCY

- The output energy level must always be less than the applied energy due to losses and storage within the system.
- The best one can hope for is that W_{out} and W_{in} are relatively close in magnitude.

EFFICIENCY

- Conservation of energy requires that
 - Energy input = energy output + energy lost or stored by the system

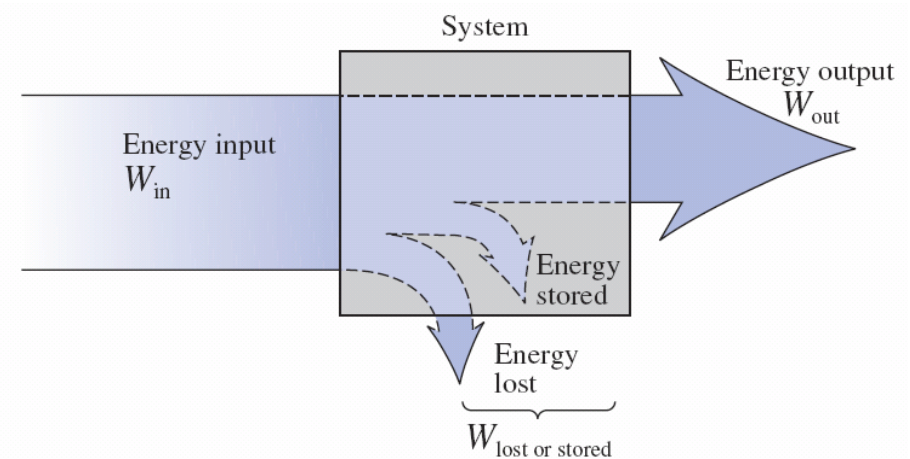


FIG. 4.20 *Energy flow through a system.*

EFFICIENCY

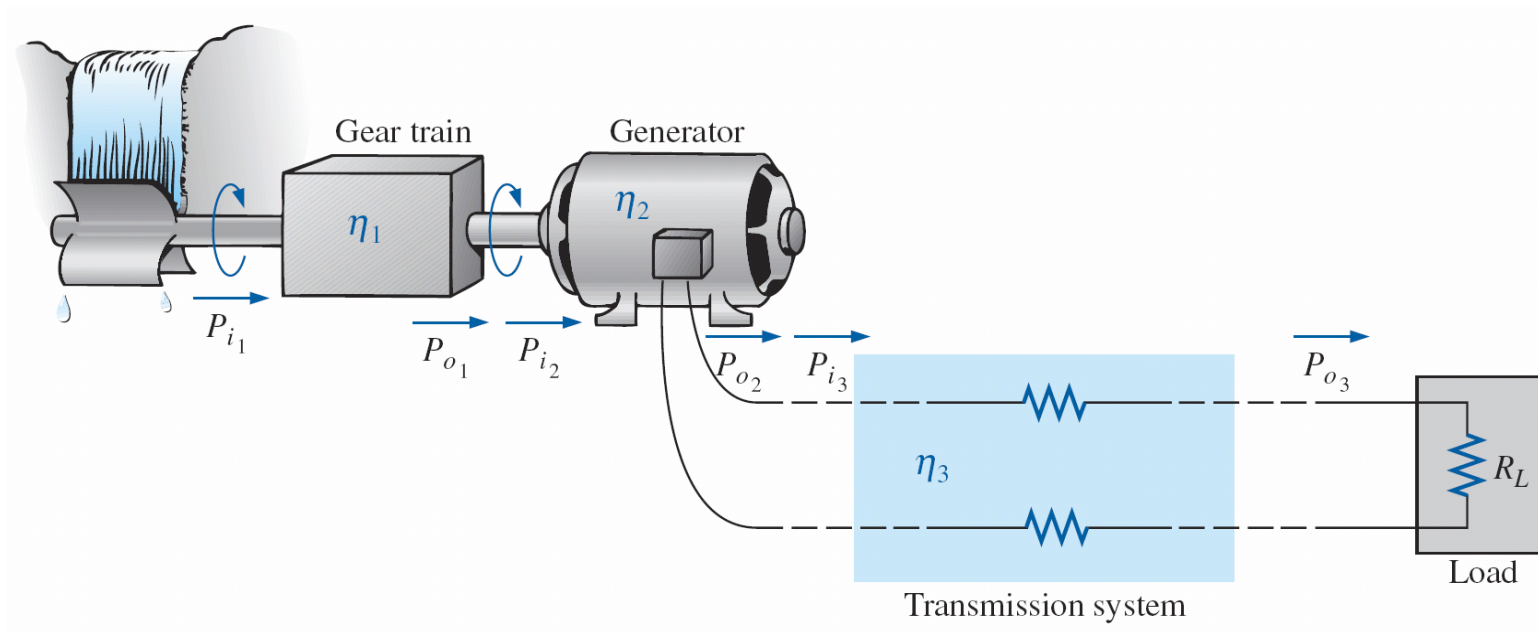


FIG. 4.21 *Basic components of a generating system.*

EFFICIENCY

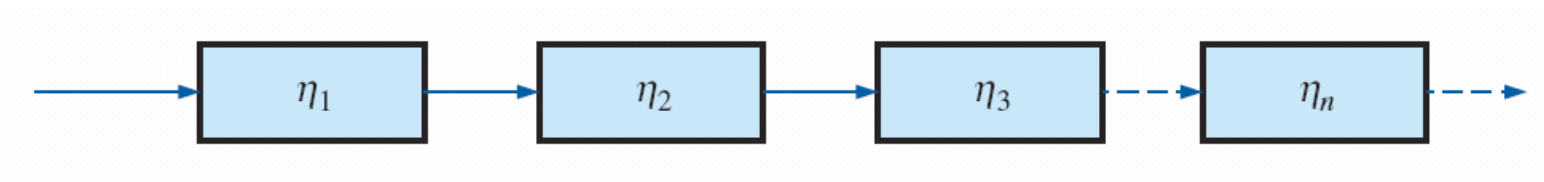


FIG. 4.22
*Cascaded
system.*

CIRCUIT BREAKERS, GFCIs, AND FUSES

- The incoming power to any large industrial plant, heavy equipment, simple circuit in the home, or meters used in the laboratory must be limited to ensure that the current through the lines is not above the rated value.

CIRCUIT BREAKERS, GFCIs, AND FUSES

- To limit the current level, fuses or circuit breakers are installed where the power enters the installation, such as in the panel in the basement of most homes at the point where the outside feeder lines enter the dwelling.

CIRCUIT BREAKERS, GFCIs, AND FUSES

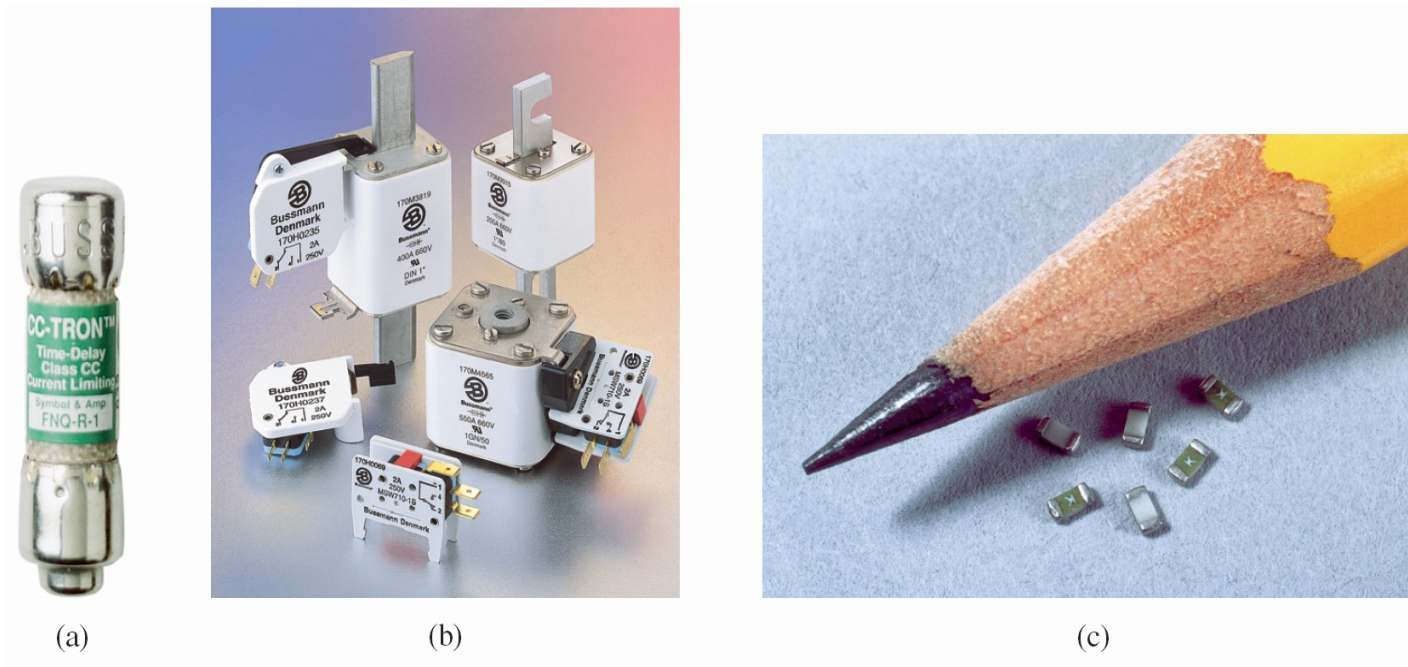


FIG. 4.23 *Fuses: (a) CC-TRON® (0–10 A); (b) Semitron (0–600 A); (c) subminiature surface-mount chip fuses.*

CIRCUIT BREAKERS, GFCIs, AND FUSES

- In homes built in recent years, fuses have been replaced by circuit breakers.
- When the current exceeds rated conditions, an electromagnet in the device will have sufficient strength to draw the connecting metallic link in the breaker out of the circuit and open the current path.

CIRCUIT BREAKERS, GFCIs, AND FUSES



FIG. 4.24 *Circuit breakers.*

CIRCUIT BREAKERS, GFCIs, AND FUSES

- The most recent National Electrical Code requires that outlets in the bathroom and other sensitive areas be of the ground fault circuit interrupt variety; designed to trip more quickly than the standard circuit breaker.

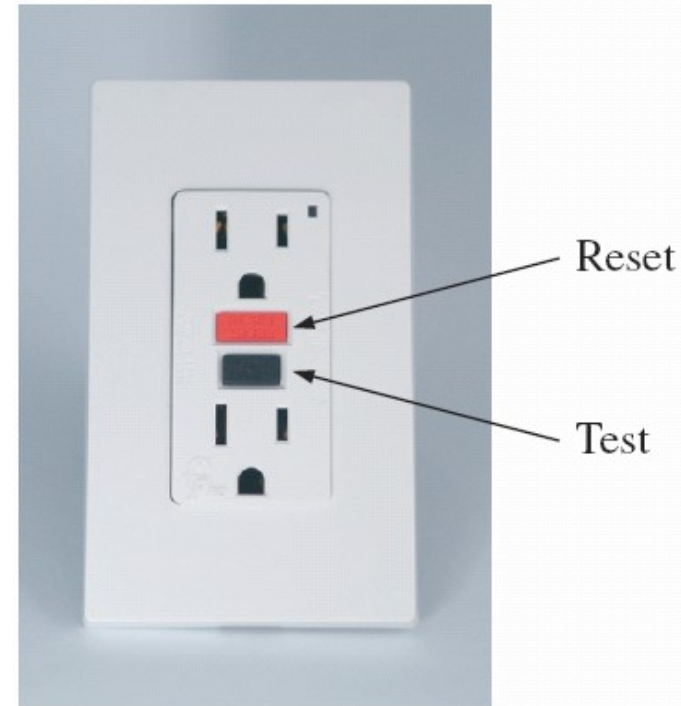
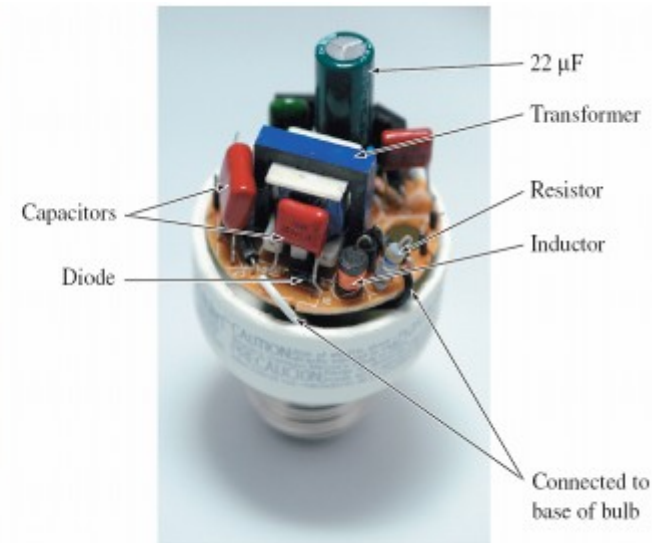
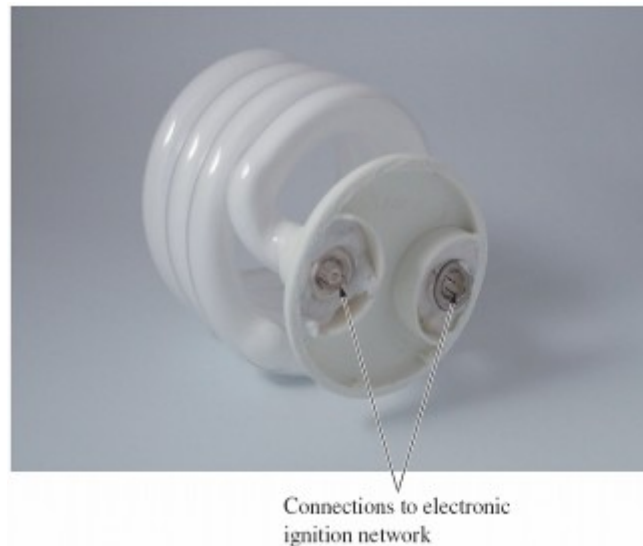


FIG. 4.23 *Ground fault circuit interrupter (GFCI): 125 V ac, 60 Hz, 15 A outlet.*

APPLICATIONS

Fluorescent versus Incandescent

FIG. 4.26 CFL bulb.
(Pearson Education)



APPLICATIONS

Microwave Oven

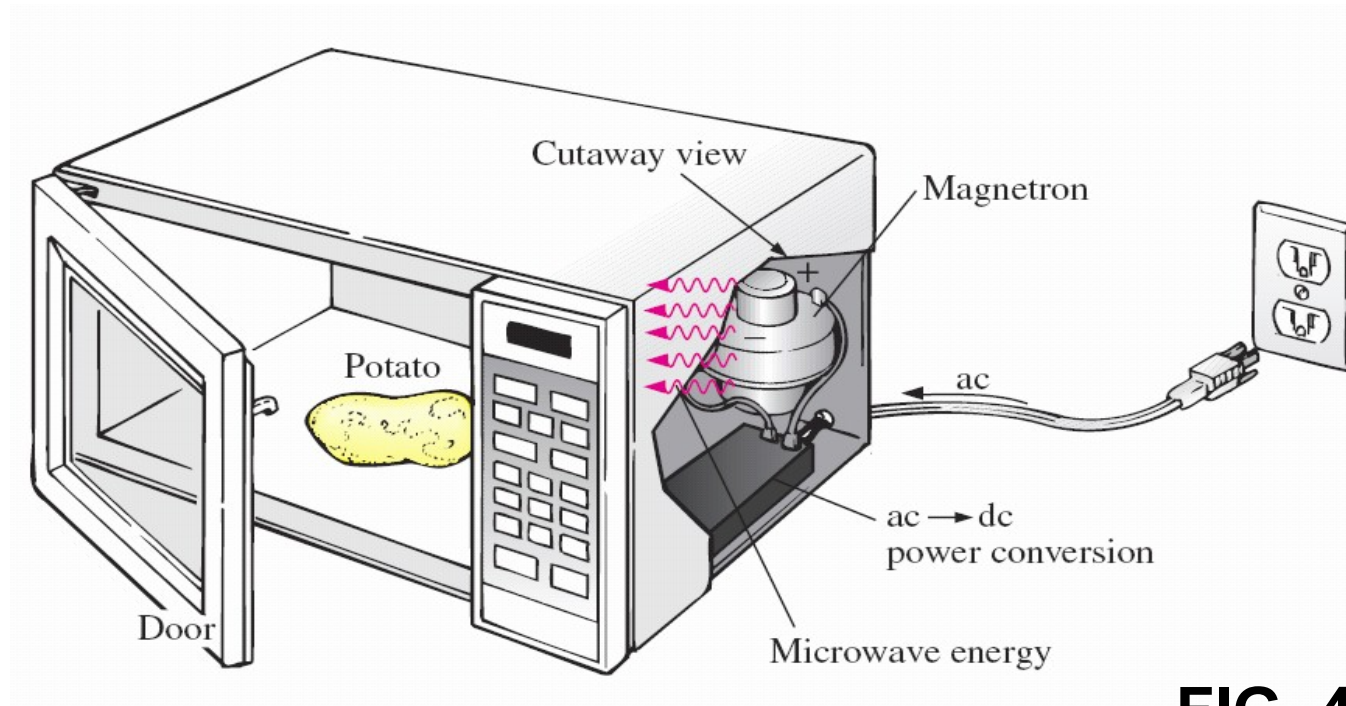


FIG. 4.28
Microwave oven.

APPLICATIONS

Household Wiring

- The one specification that defines the overall system is the maximum current that can be drawn from the power lines since the voltage is fixed at 120 V or 240 V (sometimes 208 V).
- For most older homes with a heating system other than electric, a 100 A service is the norm.

APPLICATIONS

Household Wiring

- Today, with all the electronic systems becoming commonplace in the home, many people are opting for the 200 A service even if they do not have electric heat.

APPLICATIONS

Household Wiring



FIG. 4.29 200 A service conductors: (a) 4/0 aluminum and 2/0 copper; (b) three-wire 4/0 aluminum service.

COMPUTER ANALYSIS

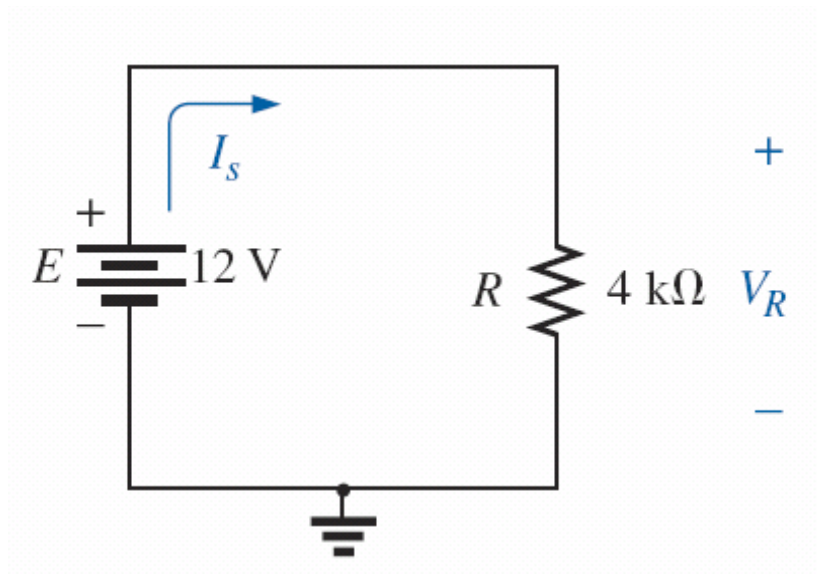


FIG. 4.32 *Circuit to be analyzed using PSpice and Multisim.*

COMPUTER ANALYSIS

PSpice

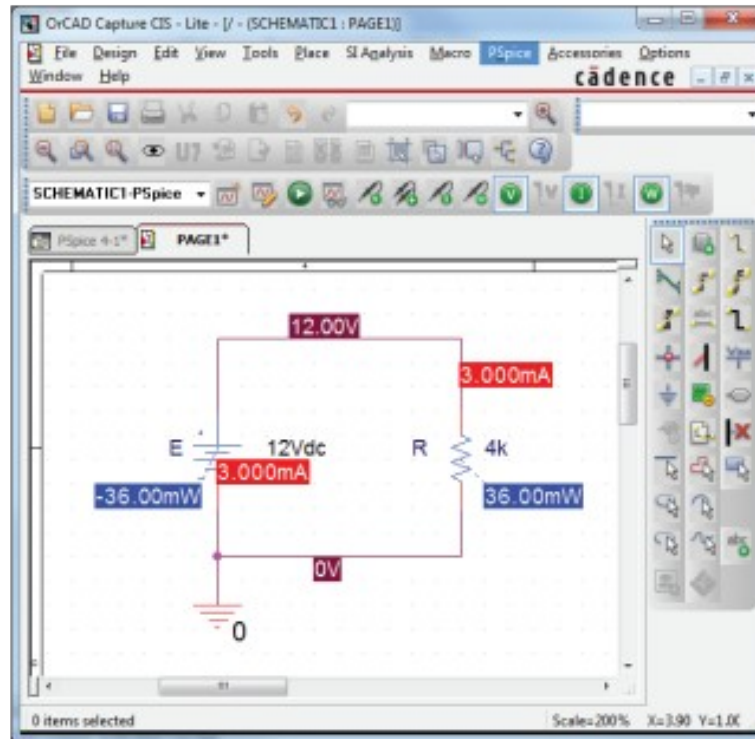


FIG. 4.33 *Using PSpice to determine the voltage, current, and power levels for the circuit in Fig. 4.28.*

COMPUTER ANALYSIS

Multisim

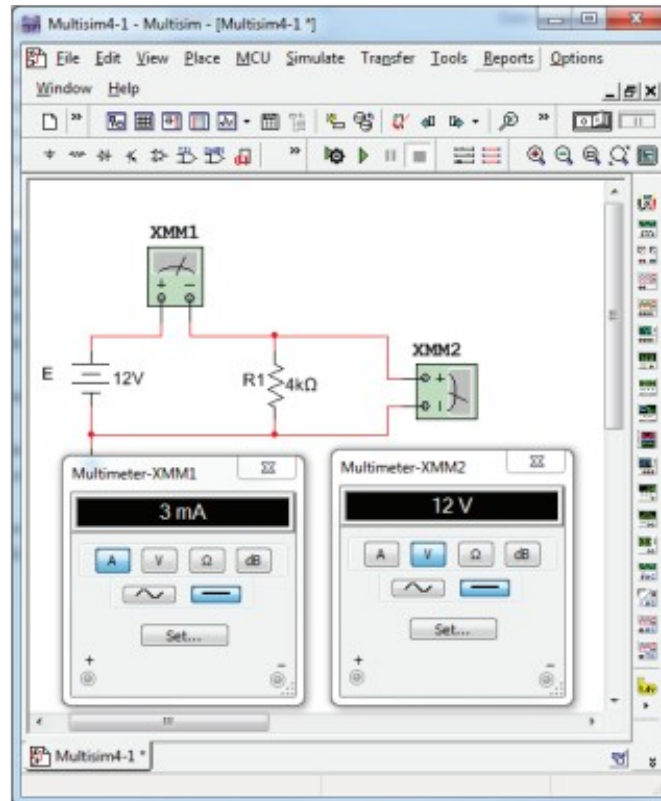
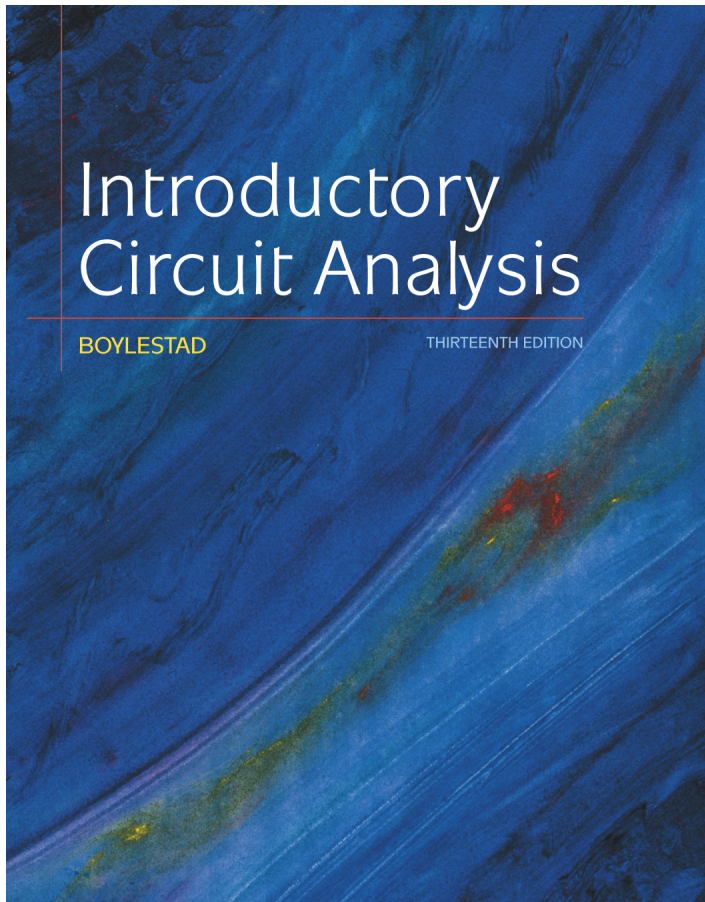


FIG. 4.34 *Using Multisim to determine the voltage and current levels for the circuit of Fig. 4.32.*

Introductory Circuit Analysis



CHAPTER 5

Series dc Circuits

OBJECTIVES

- Become familiar with the characteristics of a series circuit and how to solve for the voltage, current, and power to each of the elements.
- Develop a clear understanding of Kirchhoff's voltage law and how important it is to the analysis of electric circuits.

OBJECTIVES

- Become aware of how an applied voltage will divide among series components and how to properly apply the voltage divider rule.
- Understand the use of single- and doublesubscript notation to define the voltage levels of a network.
- Learn how to use a voltmeter, ammeter, and ohmmeter to measure the important quantities of a network.

INTRODUCTION

- Two types of current are readily available to the consumer today.
 - One is direct current (dc), in which ideally the flow of charge (current) does not change in magnitude (or direction) with time.
 - The other is sinusoidal alternating current (ac), in which the flow of charge is continually changing in magnitude (and direction) with time.

INTRODUCTION

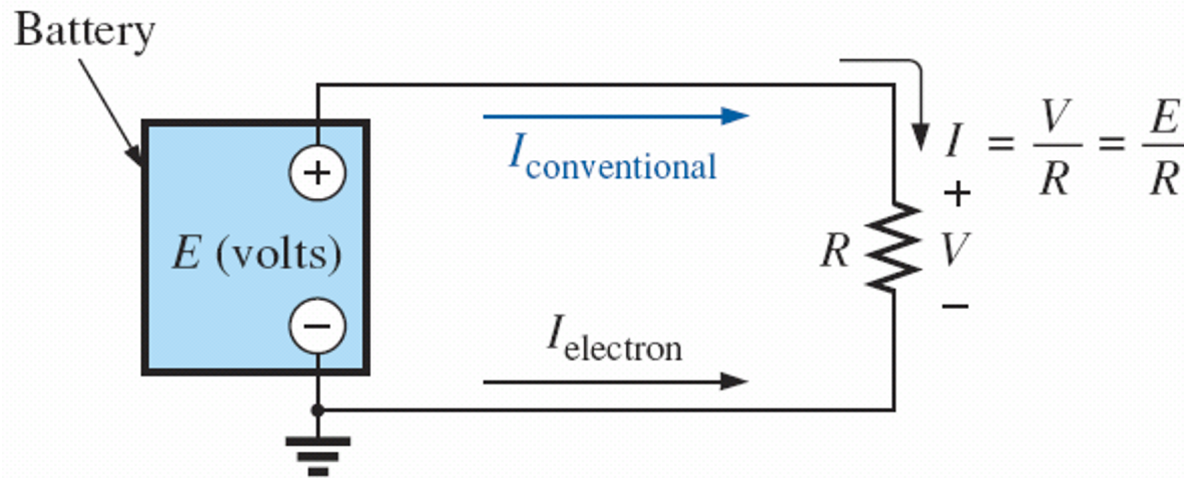
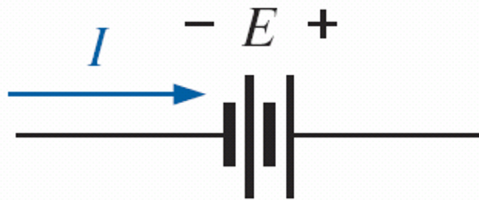


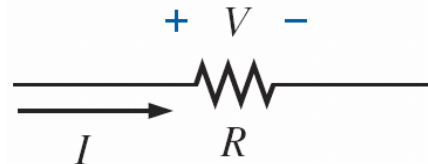
FIG. 5.1 *Introducing the basic components of an electric circuit.*

INTRODUCTION



For all one-voltage-source dc circuits

FIG. 5.2 *Defining the direction of conventional flow for single-source dc circuits.*



For any combination of voltage sources in the same dc circuit

FIG. 5.3 *Defining the polarity resulting from a conventional current I through a resistive element.*

SERIES RESISTORS

- Before the series connection is described, first recognize that every fixed resistor has only two terminals to connect in a configuration—it is therefore referred to as a two-terminal device.

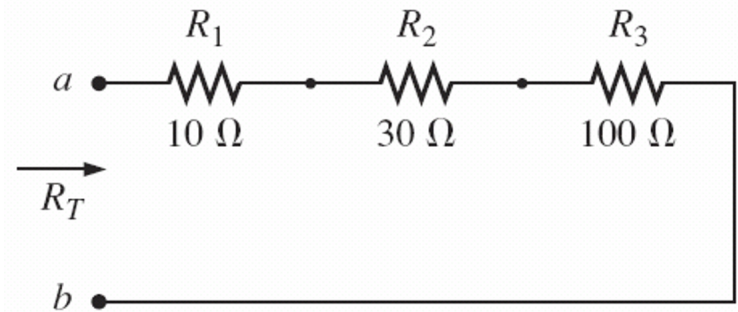


FIG. 5.4 *Series connection of resistors.*

SERIES RESISTORS

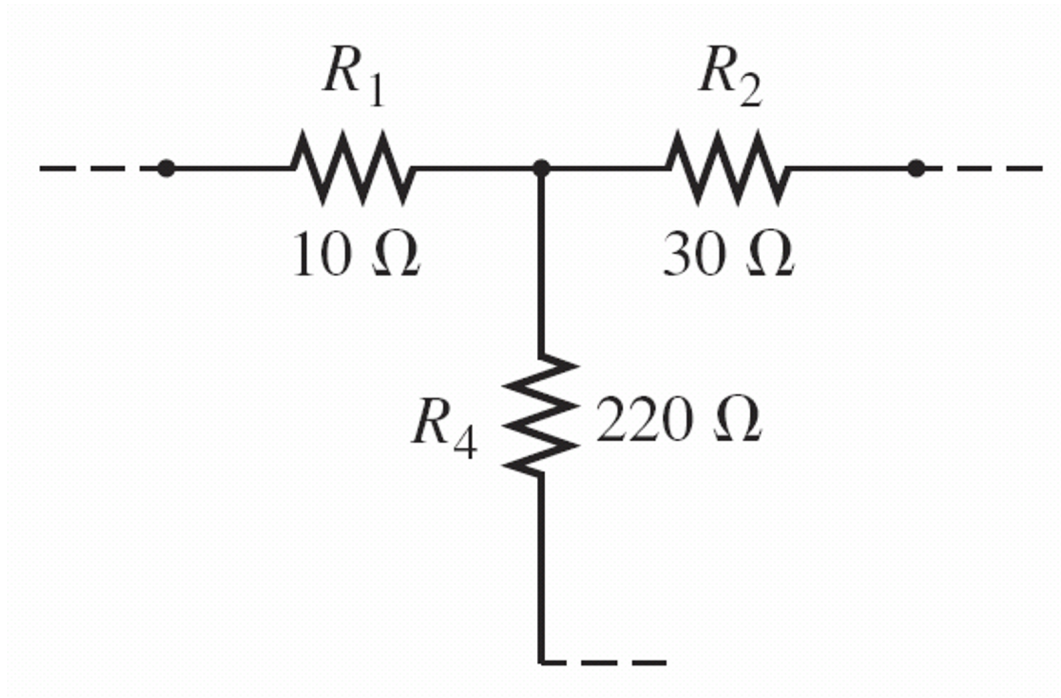


FIG. 5.5 *Configuration in which none of the resistors are in series.*

SERIES RESISTORS

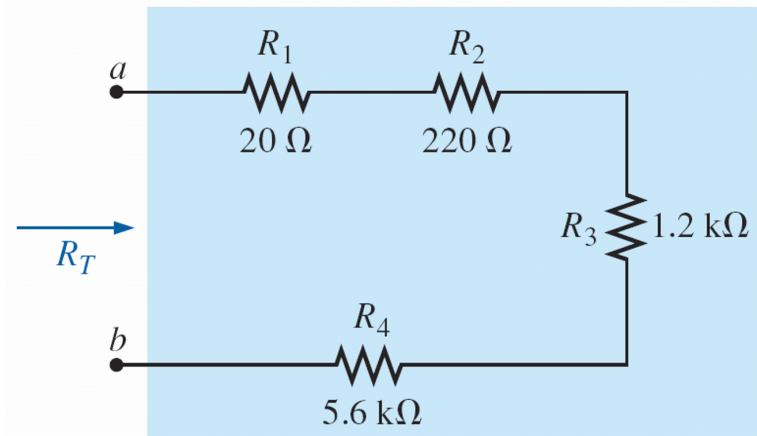


FIG. 5.6 Series connection of resistors for Example 5.1.

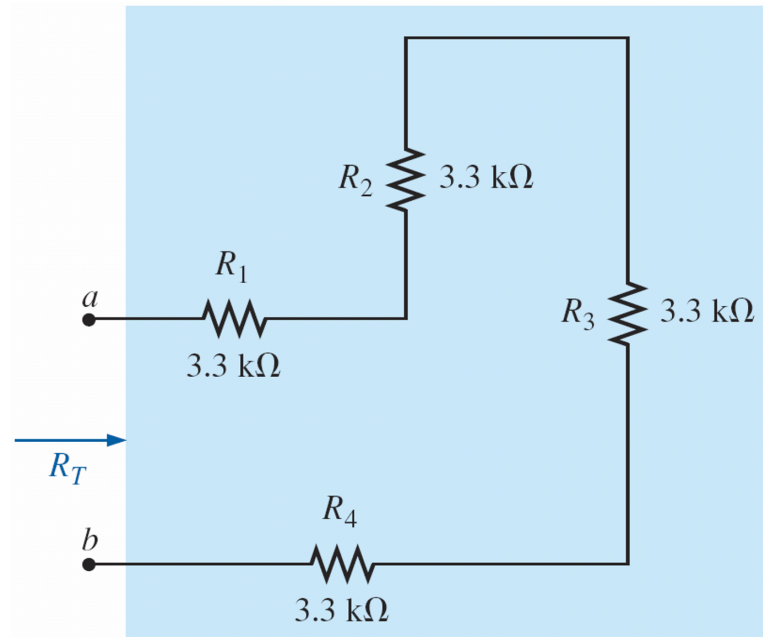


FIG. 5.7 Series connection of four resistors of the same value (Example 5.2).

SERIES RESISTORS

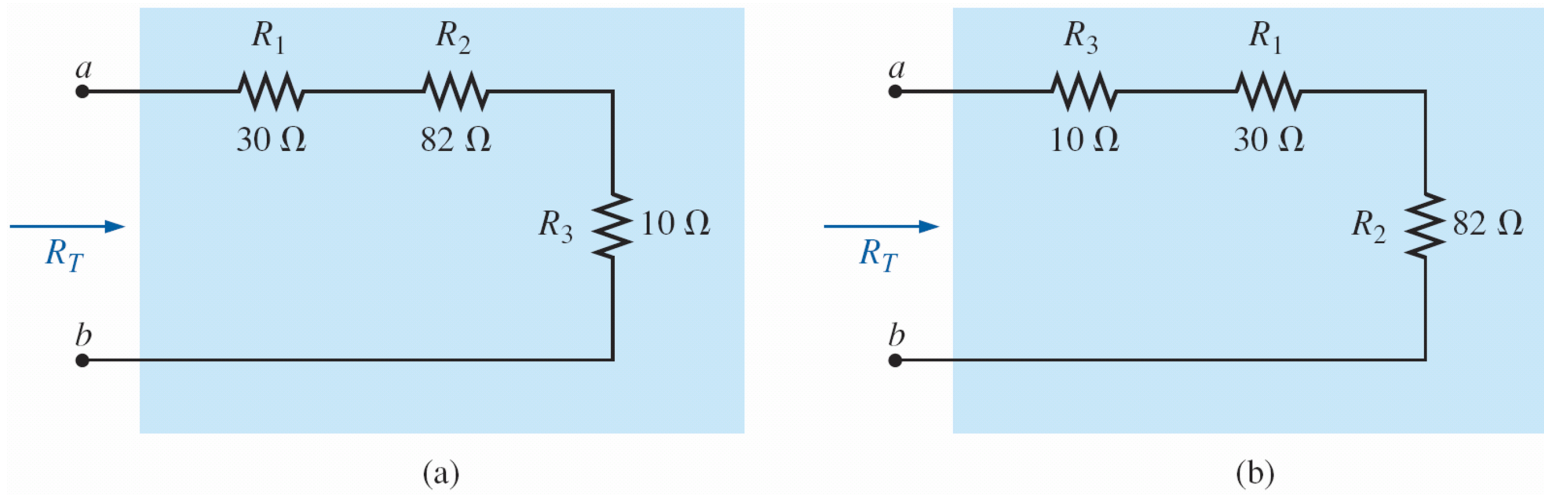


FIG. 5.8 *Two series combinations of the same elements with the same total resistance.*

SERIES RESISTORS

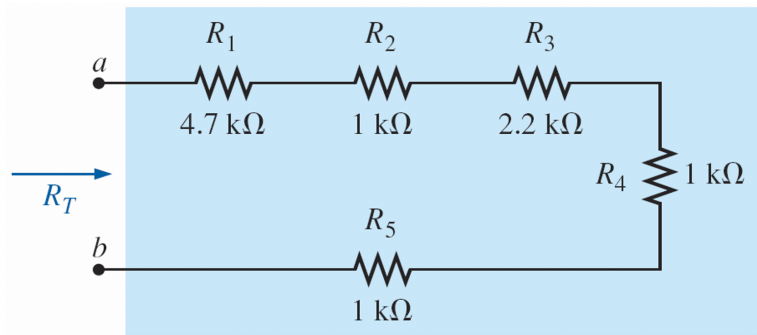


FIG. 5.9 Series combination of resistors for Example 5.3.

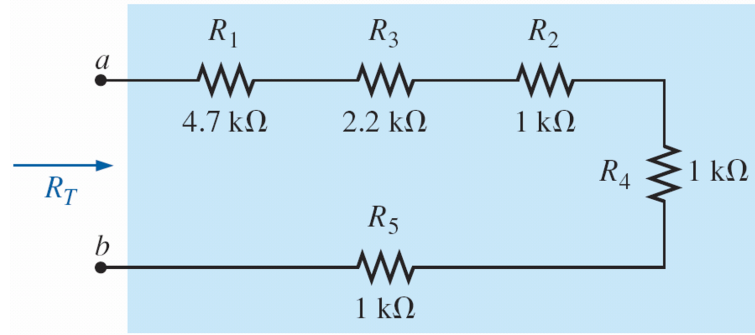


FIG. 5.10 Series circuit of Fig. 5.9 redrawn to permit the use of Eq. (5.2): $R_T = NR$.

SERIES RESISTORS

Analogies

- One analogy that works well for the series combination of elements is connecting different lengths of rope together to make the rope longer.
- Adjoining pieces of rope are connected at only one point, satisfying the definition of series elements.
- Connecting a third rope to the common point would mean that the sections of rope are no longer in a series.

SERIES RESISTORS

Instrumentation

- The total resistance of any configuration can be measured by simply connecting an ohmmeter across the access terminals.
- Since there is no polarity associated with resistance, either lead can be connected to point a, with the other lead connected to point b.

SERIES RESISTORS

Instrumentation

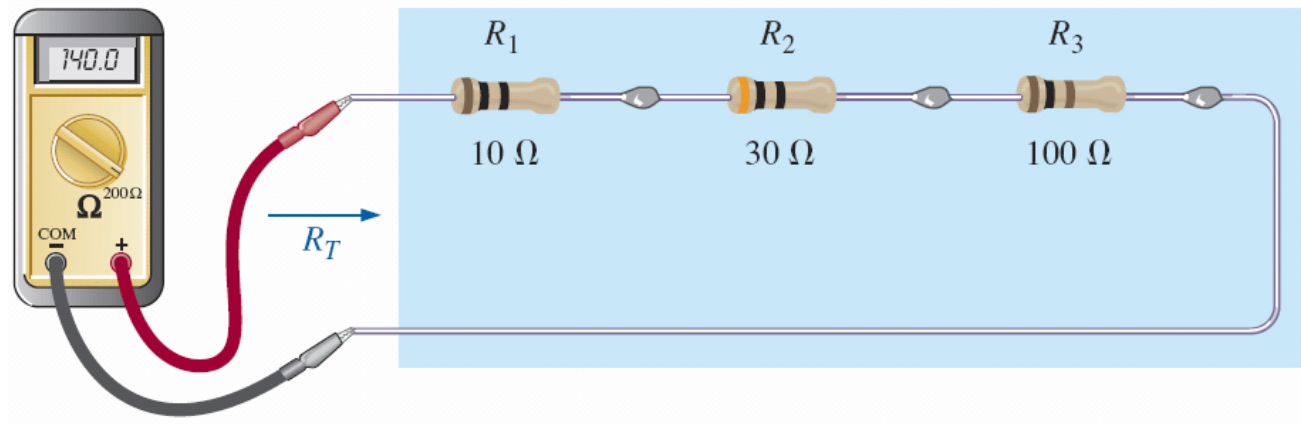


FIG. 5.11 *Using an ohmmeter to measure the total resistance of a series circuit.*

SERIES CIRCUITS

- If we now take an 8.4 V dc supply and connect it in series with the series resistors in Fig. 5.4, we have the series circuit in Fig. 5.12.

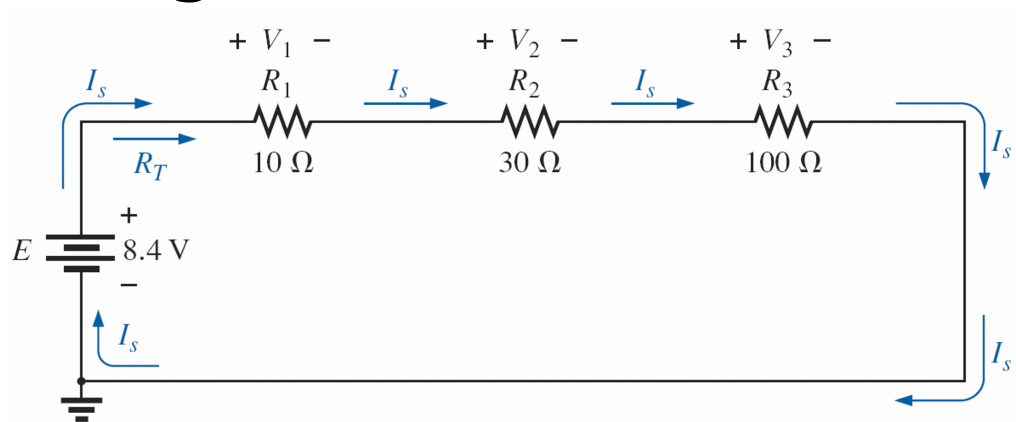


FIG. 5.12 *Schematic representation for a dc series circuit.*

SERIES CIRCUITS

- A circuit is any combination of elements that will result in a continuous flow of charge, or current, through the configuration.

SERIES CIRCUITS

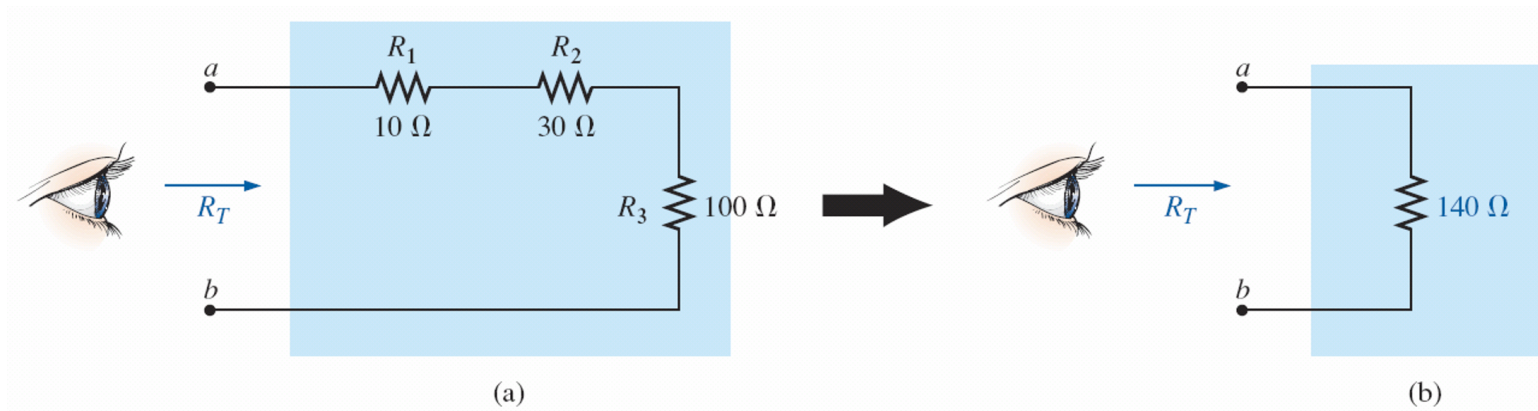


FIG. 5.13 Resistance “seen” at the terminals of a series circuit.

SERIES CIRCUITS

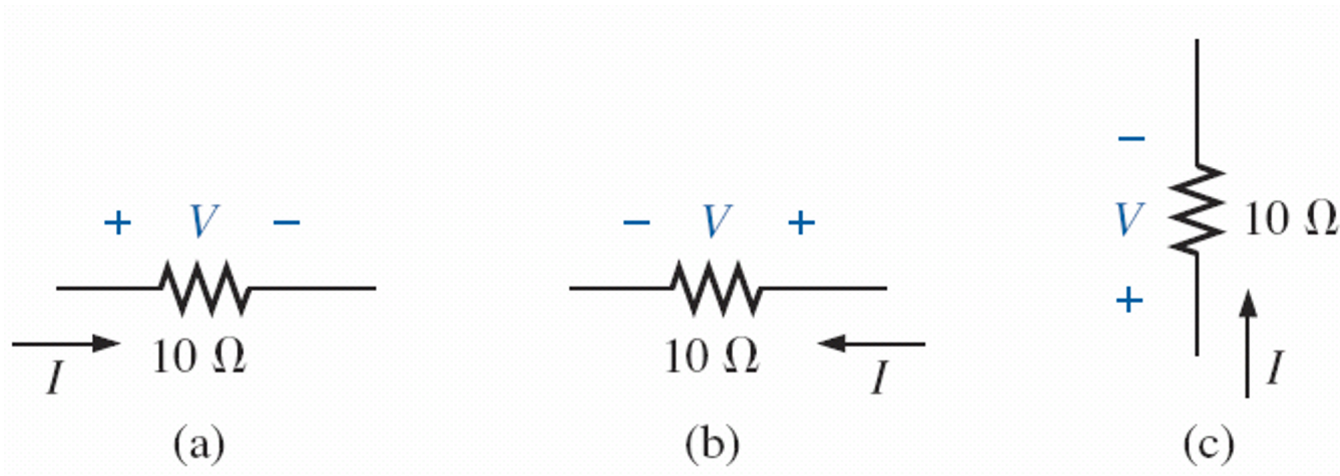


FIG. 5.14 *Inserting the polarities across a resistor as determined by the direction of the current.*

SERIES CIRCUITS

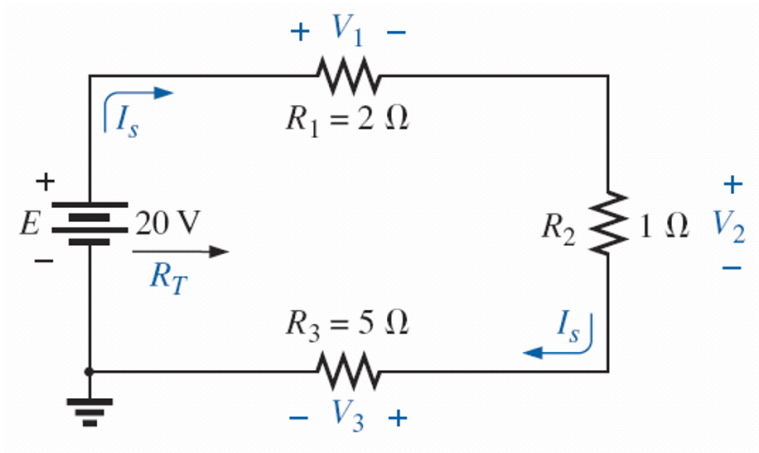


FIG. 5.15 Series circuit to be investigated in Example 5.4.

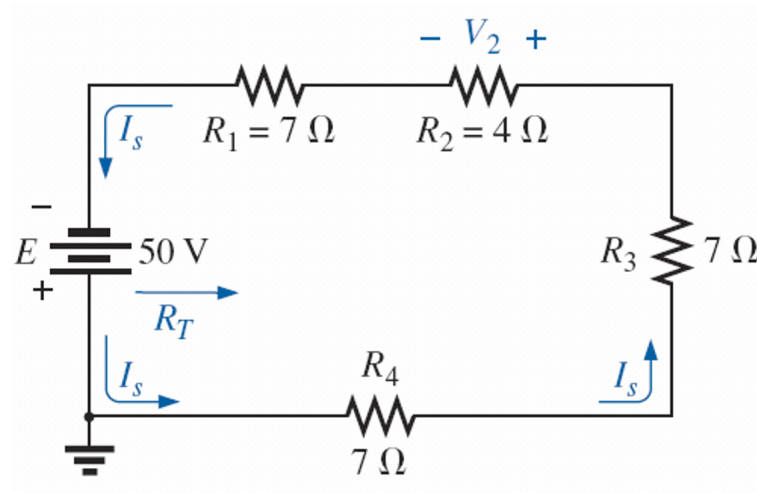


FIG. 5.16 Series circuit to be analyzed in Example 5.5.

SERIES CIRCUITS

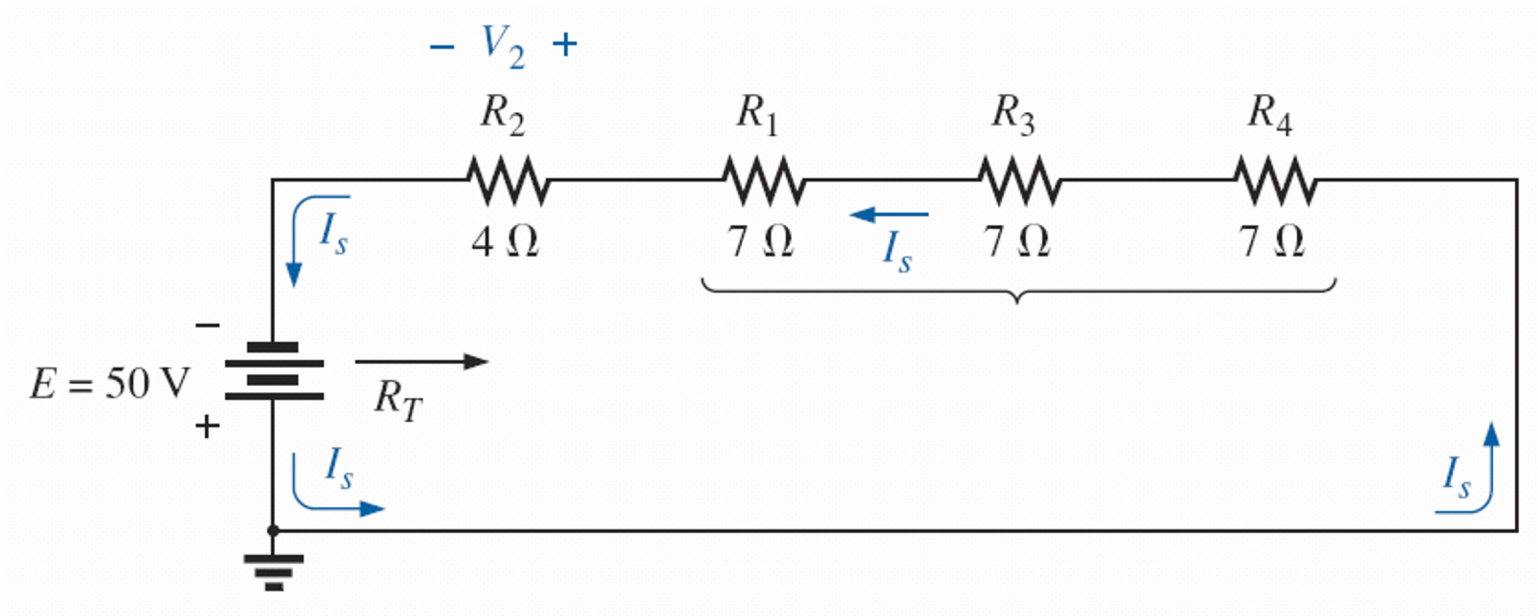


FIG. 5.17 Circuit in Fig. 5.16 redrawn to permit the use of Eq. (5.2).

SERIES CIRCUITS

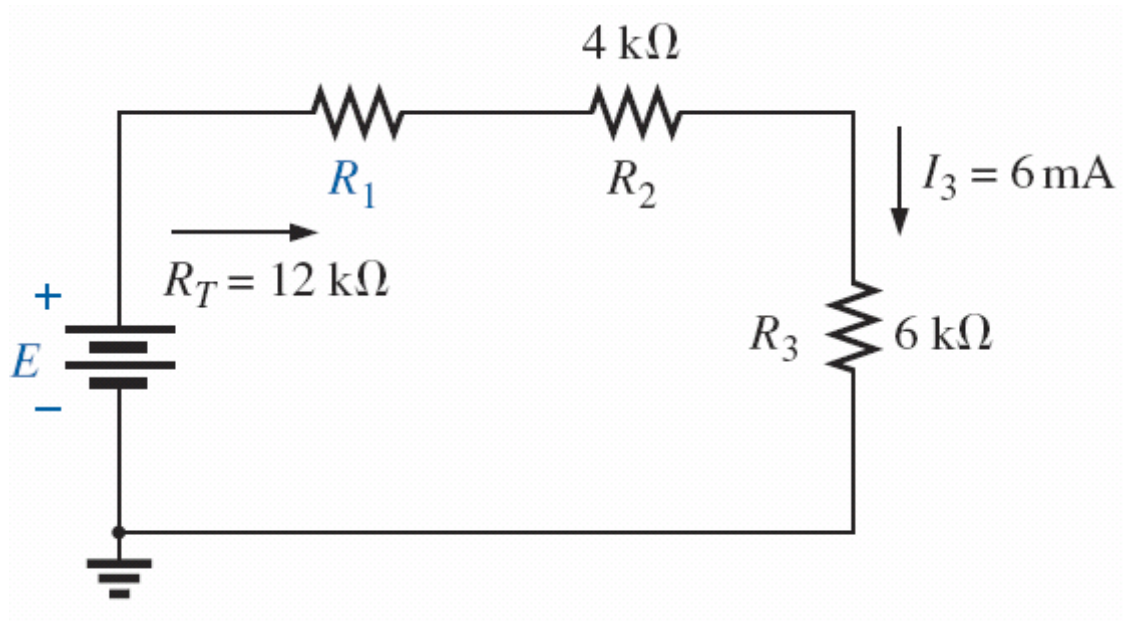


FIG. 5.18 *Series circuit to be analyzed in Example 5.6.*

SERIES CIRCUITS

Analogies

- The analogies used earlier to define the series connection are also excellent for the current of a series circuit.
- For instance, for the seriesconnected ropes, the stress on each rope is the same as they try to hold the heavy weight.

SERIES CIRCUITS

Analogies

- For the water analogy, the flow of water is the same through each section of hose as the water is carried to its destination.

SERIES CIRCUITS

Instrumentation

- Another important concept to remember is:
 - The insertion of any meter in a circuit will affect the circuit.
- Furthermore, it is particularly helpful in the laboratory to realize that the voltages of a circuit can be measured without disturbing (breaking the connections in) the circuit.

SERIES CIRCUITS

Instrumentation

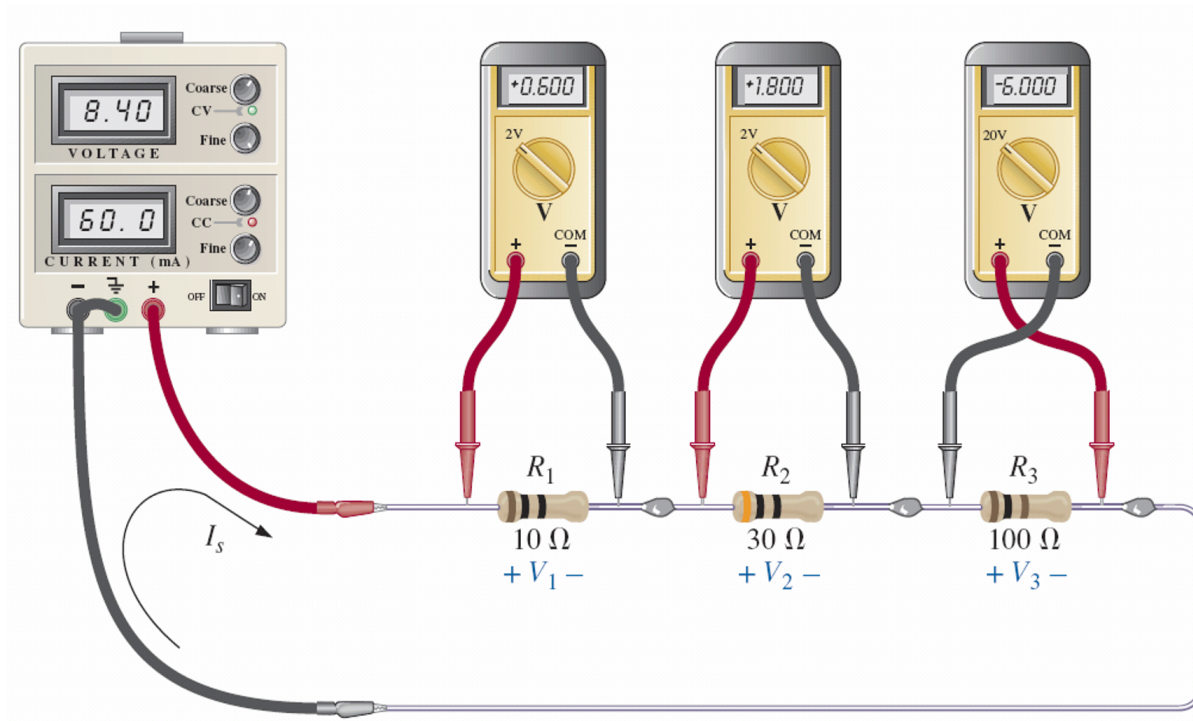


FIG. 5.19 *Using voltmeters to measure the voltages across the resistors in Fig. 5.12.*

SERIES CIRCUITS

Instrumentation

- In general, when using a voltmeter, start with a scale that will ensure that the reading is less than the maximum value of the scale. Then work your way down in scales until the reading with the highest level of precision is obtained.

SERIES CIRCUITS

Instrumentation

- Turning our attention to the current of the circuit, we find that using an ammeter to measure the current of a circuit requires that the circuit be broken at some point and the meter inserted in series with the branch in which the current is to be determined.

SERIES CIRCUITS

Instrumentation

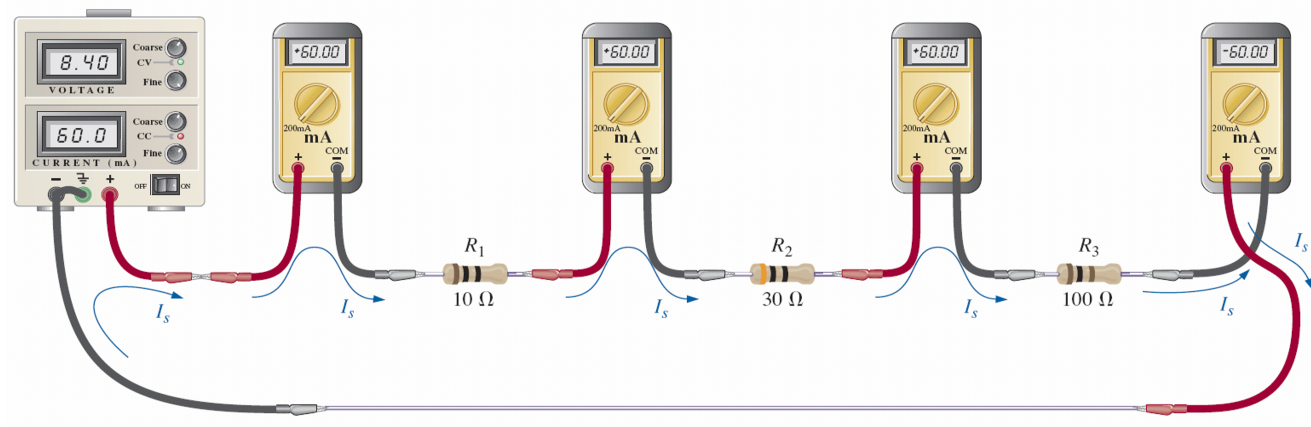


FIG. 5.20 *Measuring the current throughout the series circuit in Fig. 5.12.*

POWER DISTRIBUTION IN A SERIES CIRCUIT

- In any electrical system, the power applied will equal the power dissipated or absorbed.
- For any series circuit the power applied by the dc supply must equal that dissipated by the resistive elements.

POWER DISTRIBUTION IN A SERIES CIRCUIT

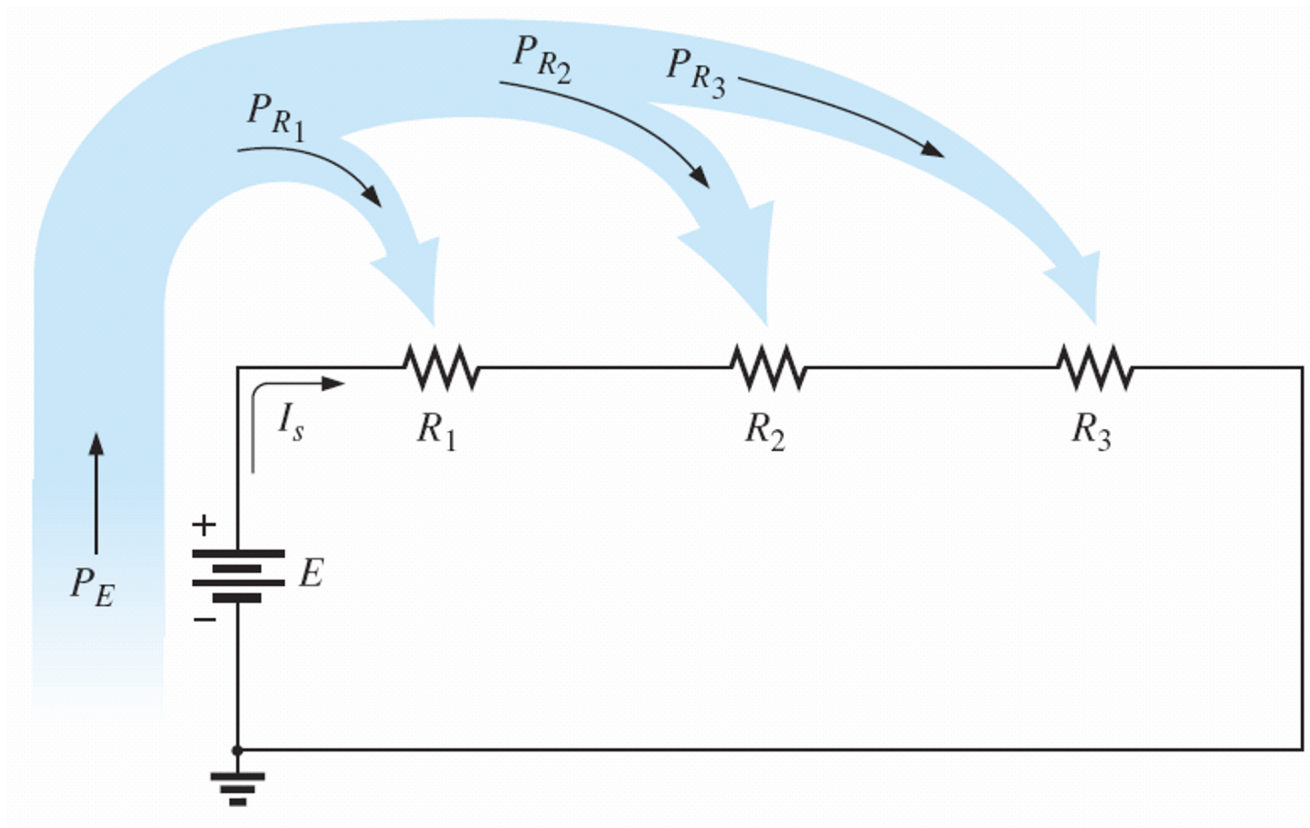


FIG. 5.21 *Power distribution in a series circuit.*

POWER DISTRIBUTION IN A SERIES CIRCUIT

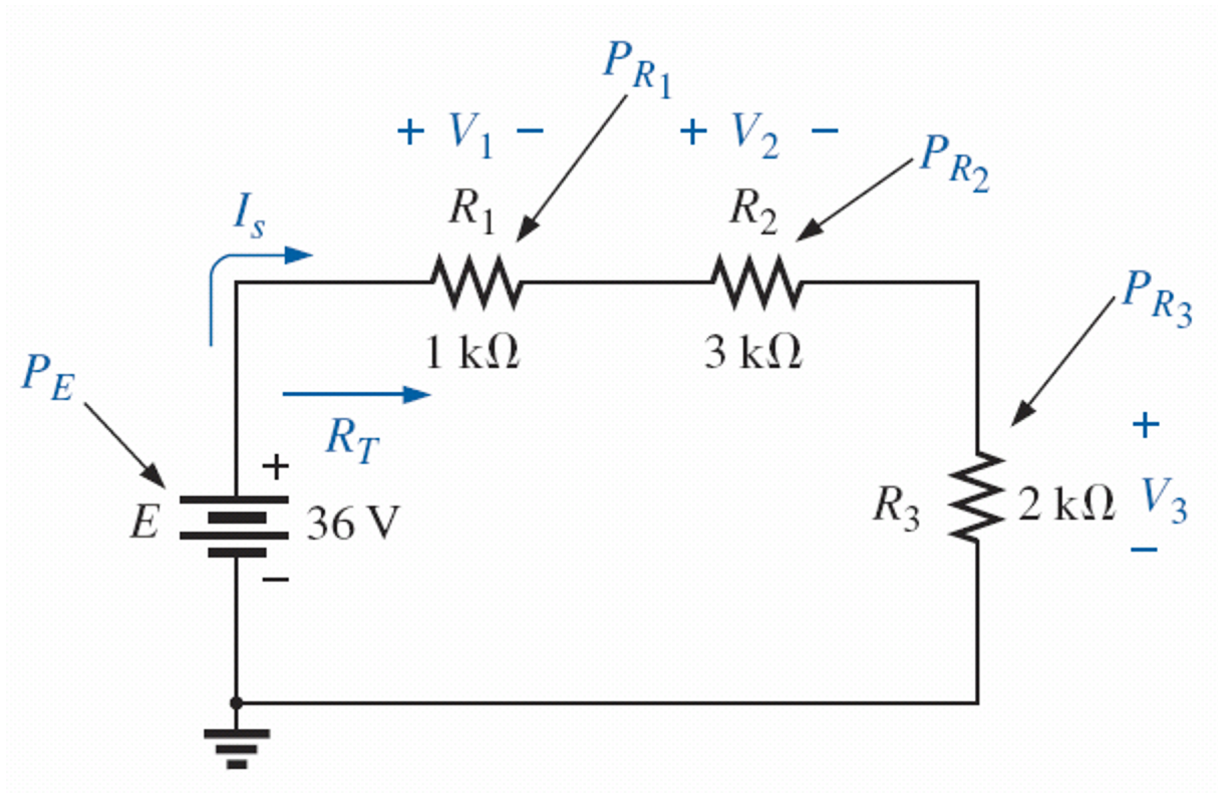


FIG. 5.22 *Series circuit to be investigated in Example 5.7.*

VOLTAGE SOURCES IN SERIES

- Voltage sources can be connected in series, to increase or decrease the total voltage applied to a system.
- The net voltage is determined by summing the sources with the same polarity and subtracting the total of the sources with the opposite polarity.
- The net polarity is the polarity of the larger sum.

VOLTAGE SOURCES IN SERIES

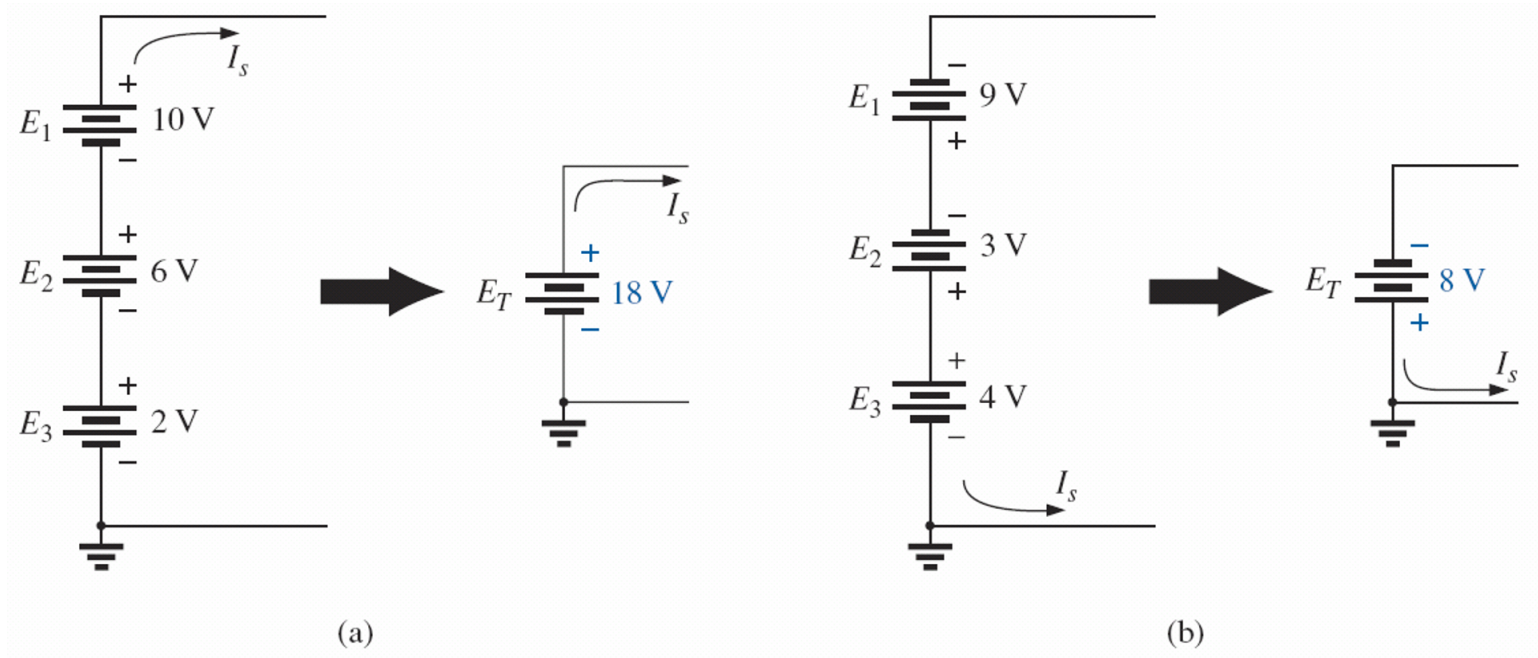


FIG. 5.23 Reducing series dc voltage sources to a single source.

VOLTAGE SOURCES IN SERIES

Instrumentation

- The connection of batteries in series to obtain a higher voltage is common in much of today's portable electronic equipment.

VOLTAGE SOURCES IN SERIES

Instrumentation

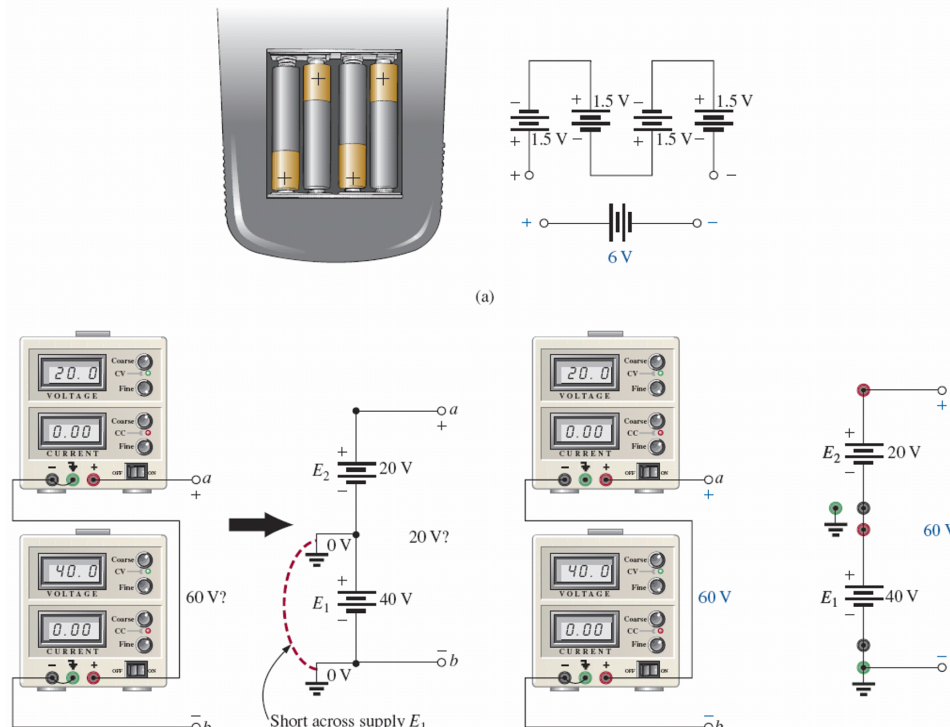


FIG. 5.24 Series connection of dc supplies: (a) four 1.5 V batteries in series to establish a terminal voltage of 6 V; (b) incorrect connections for two series dc supplies; (c) correct connection of two series supplies to establish 60 V at the output terminals.

KIRCHHOFF'S VOLTAGE LAW

- The law, called Kirchhoff's voltage law (KVL), was developed by Gustav Kirchhoff in the mid-1800s.
- It is a cornerstone of the entire field and, in fact, will never be outdated or replaced.

KIRCHHOFF'S VOLTAGE LAW

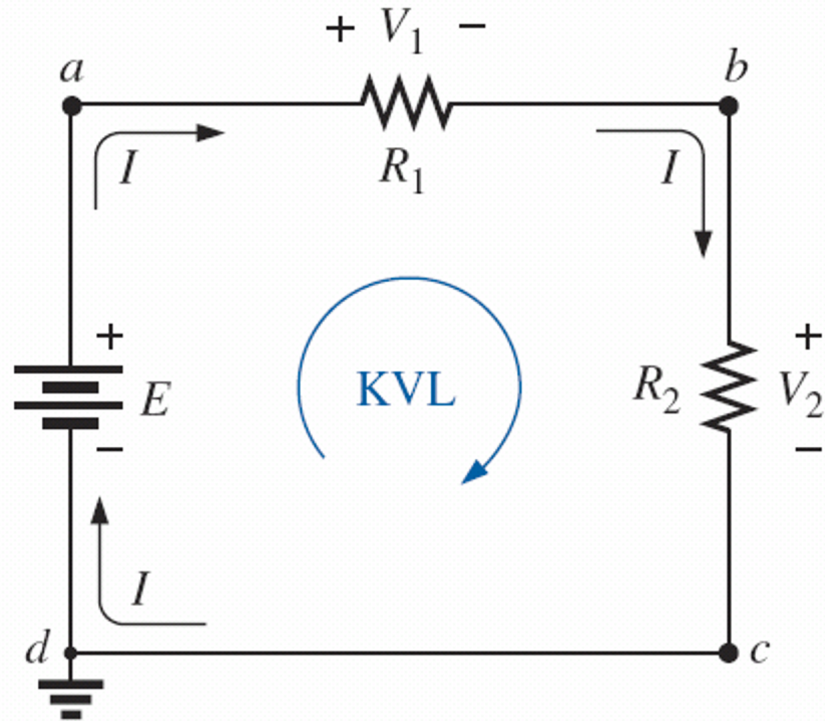


FIG. 5.26 Applying Kirchhoff's voltage law to a series dc circuit.

KIRCHHOFF'S VOLTAGE LAW

- The law specifies that the algebraic sum of the potential rises and drops around a closed path (or closed loop) is zero.

KIRCHHOFF'S VOLTAGE LAW

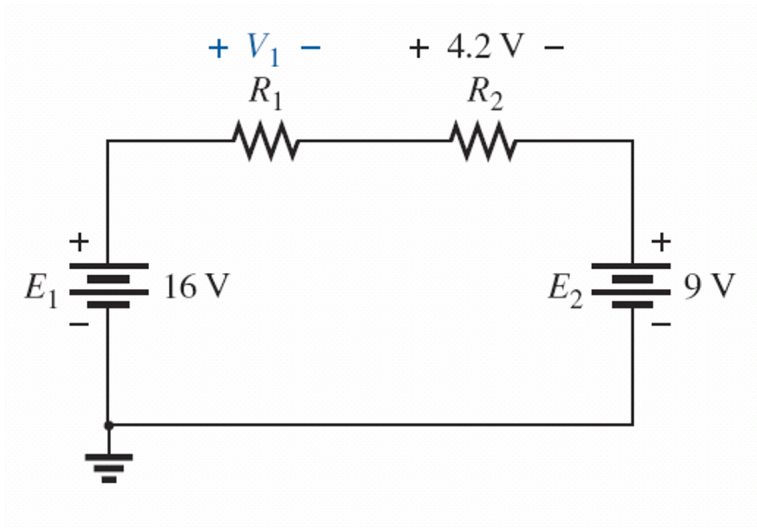


FIG. 5.27 Series circuit to be examined in Example 5.8.

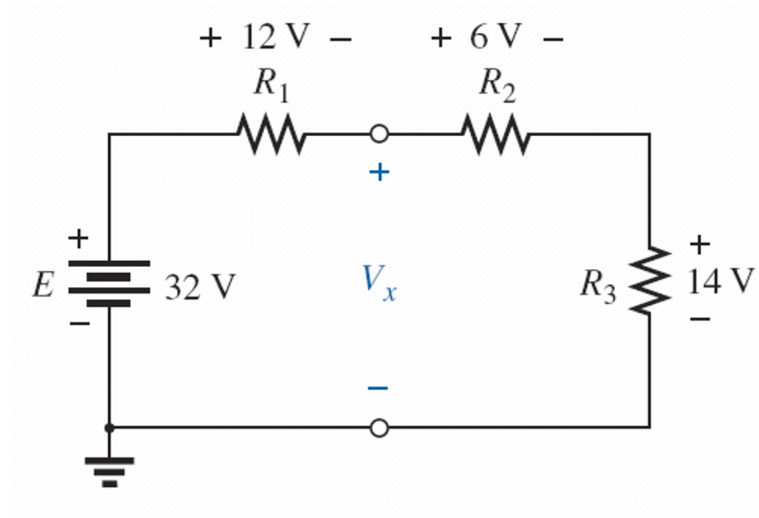


FIG. 5.28 Series dc circuit to be analyzed in Example 5.9.

KIRCHHOFF'S VOLTAGE LAW

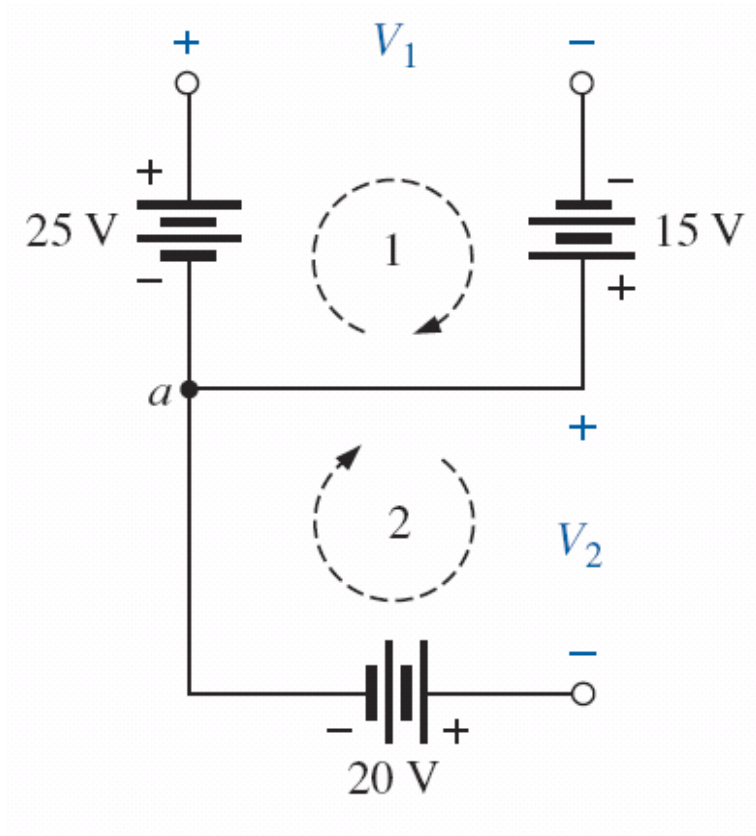


FIG. 5.29

Combination of voltage sources to be examined in Example 5.10.

KIRCHHOFF'S VOLTAGE LAW

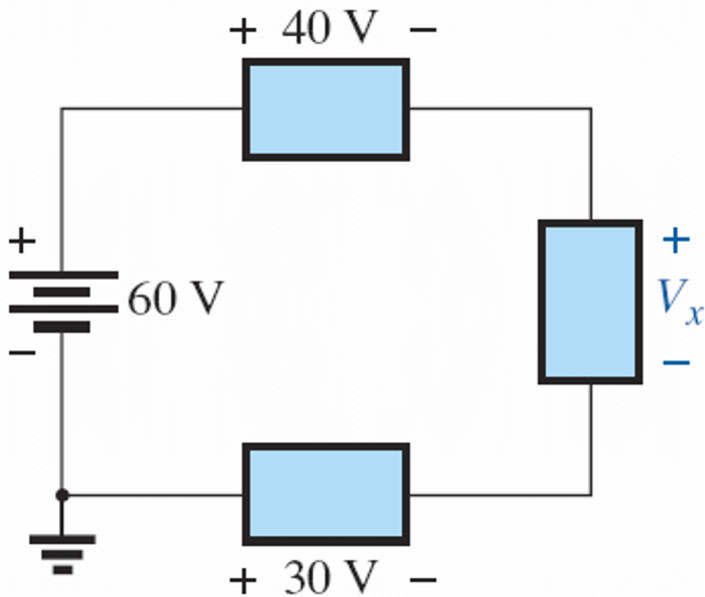


FIG. 5.30 Series configuration to be examined in Example 5.11.

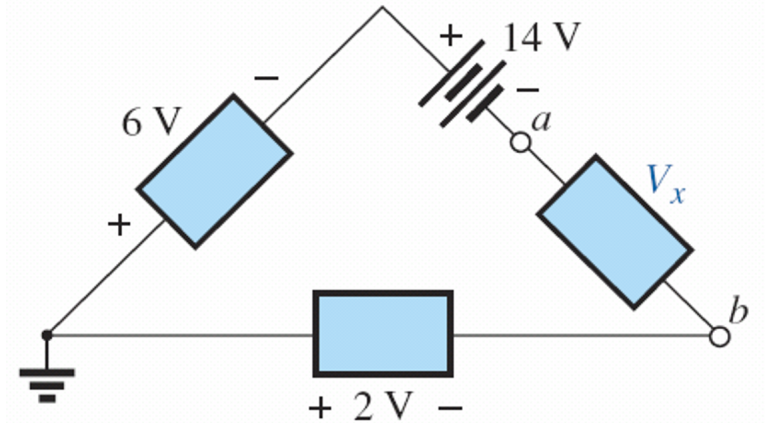


FIG. 5.31 Applying Kirchhoff's voltage law to a circuit in which the polarities have not been provided for one of the voltages (Example 5.12).

KIRCHHOFF'S VOLTAGE LAW

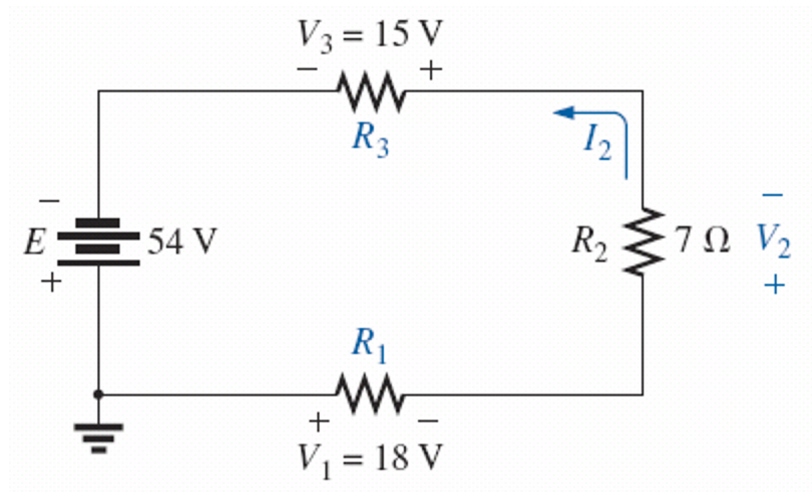


FIG. 5.32 *Series configuration to be examined in Example 5.13.*

VOLTAGE DIVISION IN A SERIES CIRCUIT

- The previous section demonstrated that the sum of the voltages across the resistors of a series circuit will always equal the applied voltage.
- It cannot be more or less than that value.
- The next question is, how will a resistor's value affect the voltage across the resistor?

VOLTAGE DIVISION IN A SERIES CIRCUIT

- It turns out that the voltage across series resistive elements will divide as the magnitude of the resistance levels.
- In other words, in a series resistive circuit, the larger the resistance, the more of the applied voltage it will capture.
- In addition, the ratio of the voltages across series resistors will be the same as the ratio of their resistance levels.

VOLTAGE DIVISION IN A SERIES CIRCUIT

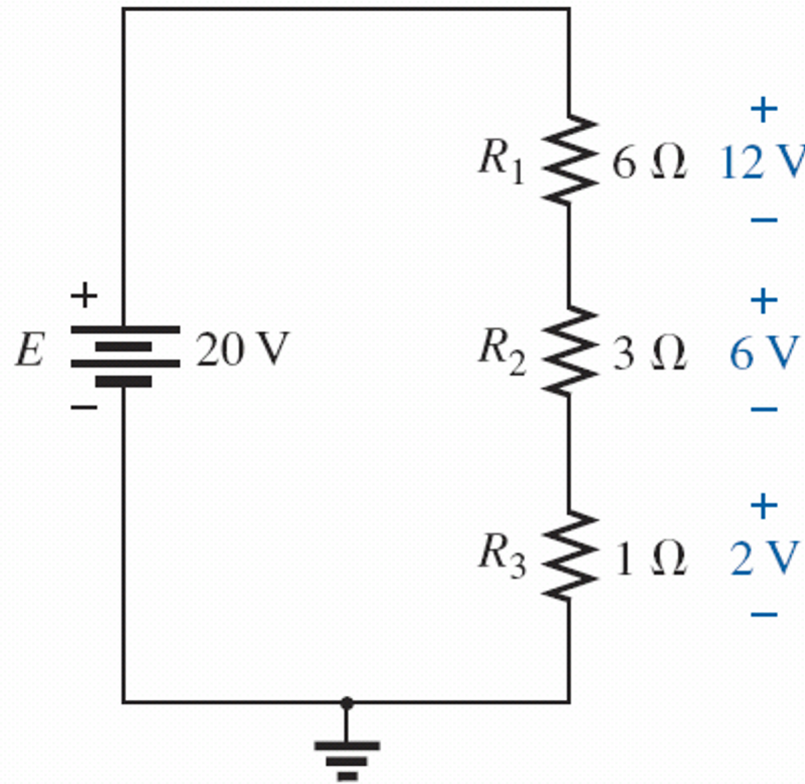


FIG. 5.33 *Example 5.15.*

VOLTAGE DIVISION IN A SERIES CIRCUIT

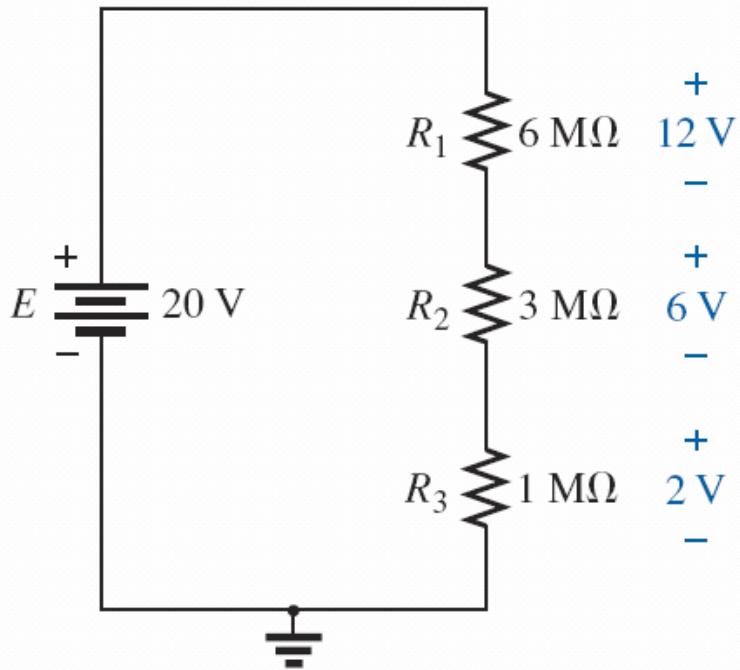


FIG. 5.34 *The ratio of the resistive values determines the voltage division of a series dc circuit.*

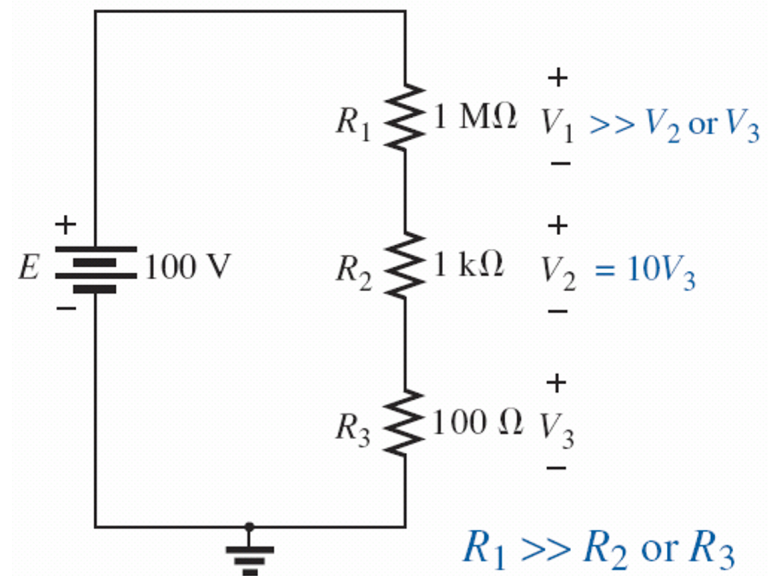


FIG. 5.35 *The largest of the series resistive elements will capture the major share of the applied voltage.*

VOLTAGE DIVISION IN A SERIES CIRCUIT: Voltage Divider Rule

- The voltage divider rule (VDR) permits the determination of the voltage across a series resistor without first having to determine the current of the circuit.

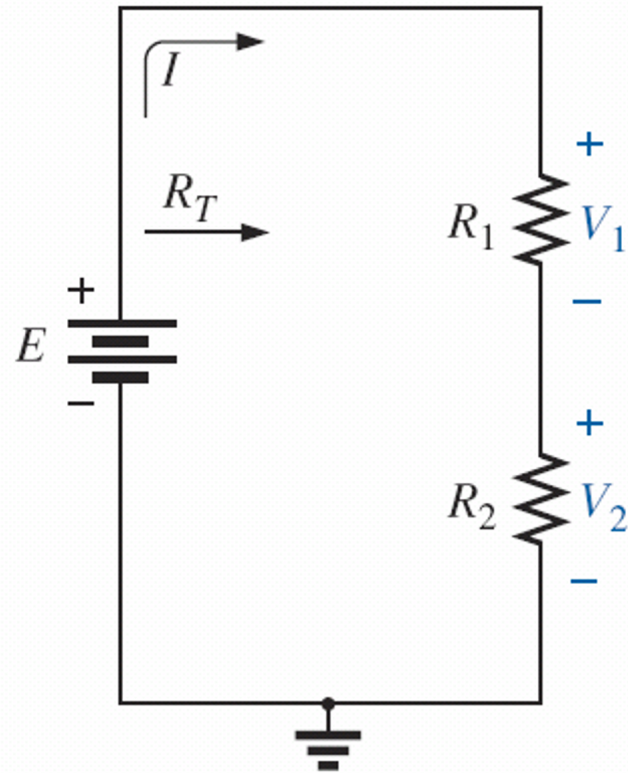


FIG. 5.36 *Developing the voltage divider rule.*

VOLTAGE DIVISION IN A SERIES CIRCUIT: Voltage Divider Rule

- The voltage divider rule states that the voltage across a resistor in a series circuit is equal to the value of that resistor times the total applied voltage divided by the total resistance of the series configuration.

VOLTAGE DIVISION IN A SERIES CIRCUIT: Voltage Divider Rule

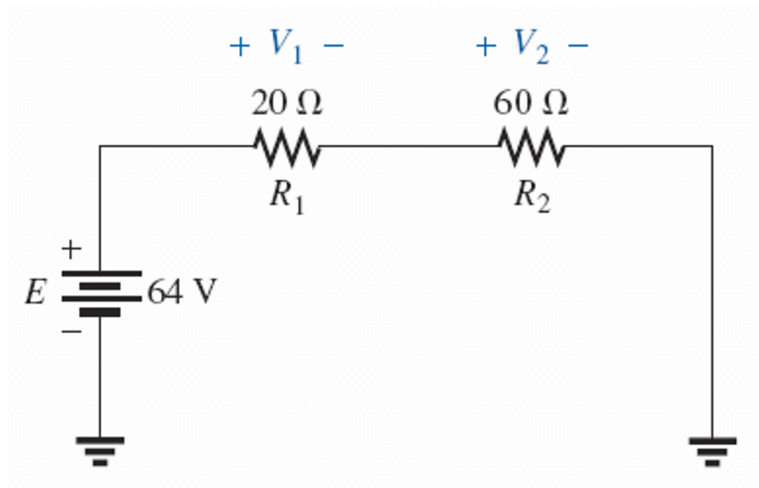


FIG. 5.37 Series circuit to be examined using the voltage divider rule in Example 5.15.

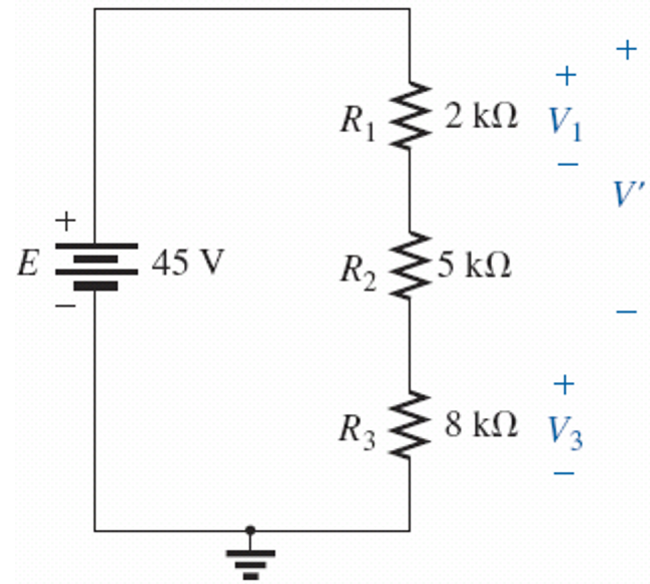


FIG. 5.38 Series circuit to be investigated in Examples 5.16 and 5.17.

VOLTAGE DIVISION IN A SERIES CIRCUIT: Voltage Divider Rule

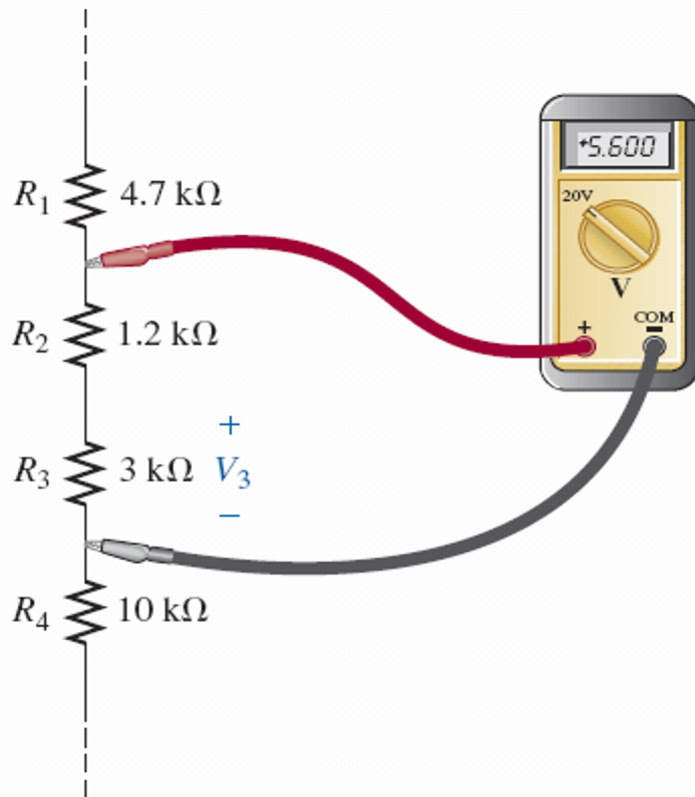


FIG. 5.39 Voltage divider action for Example 5.18.

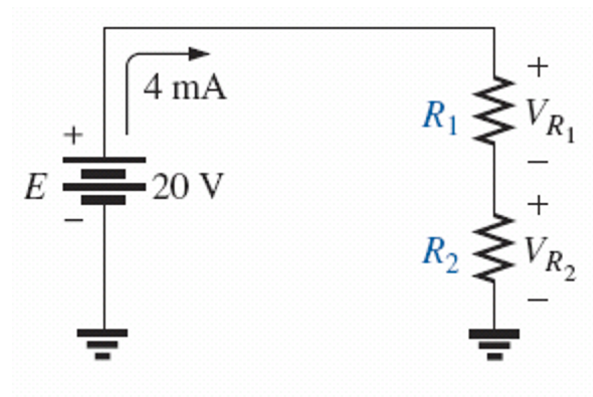


FIG. 5.40
Designing a voltage divider circuit (Example 5.19).

INTERCHANGING SERIES ELEMENTS

- The elements of a series circuit can be interchanged without affecting the total resistance, current, or power to each element.

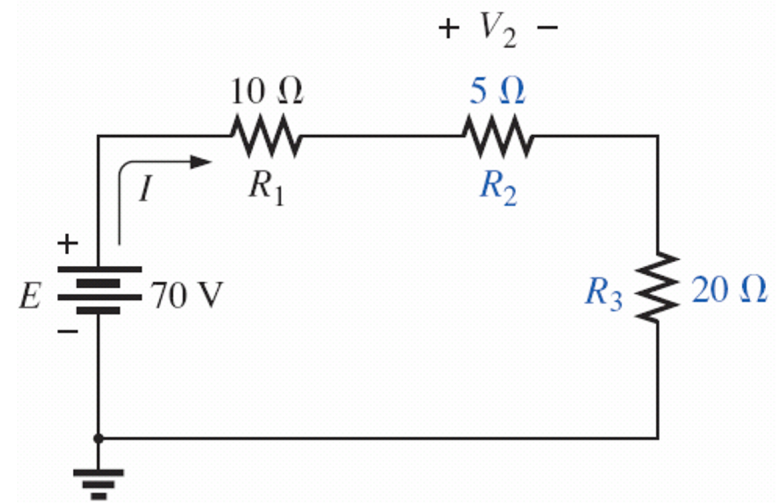


FIG. 5.41 Series dc circuit with elements to be interchanged.

INTERCHANGING SERIES ELEMENTS

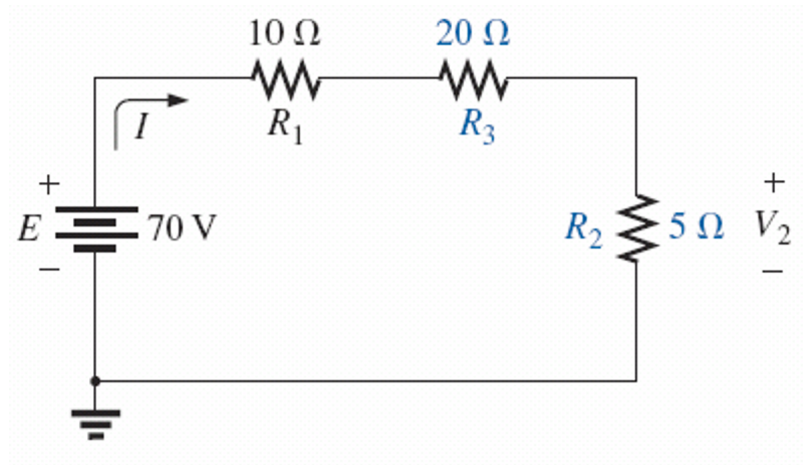


FIG. 5.42 *Circuit in Fig. 5.41 with R_2 and R_3 interchanged.*

INTERCHANGING SERIES ELEMENTS

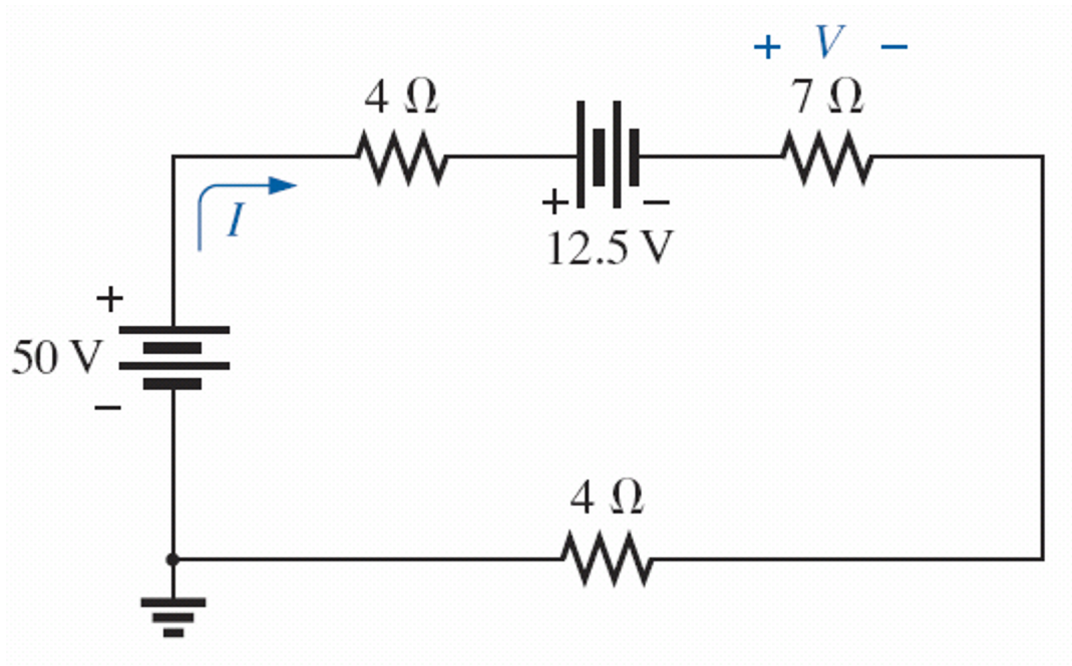


FIG. 5.43
Example 5.21.

INTERCHANGING SERIES ELEMENTS

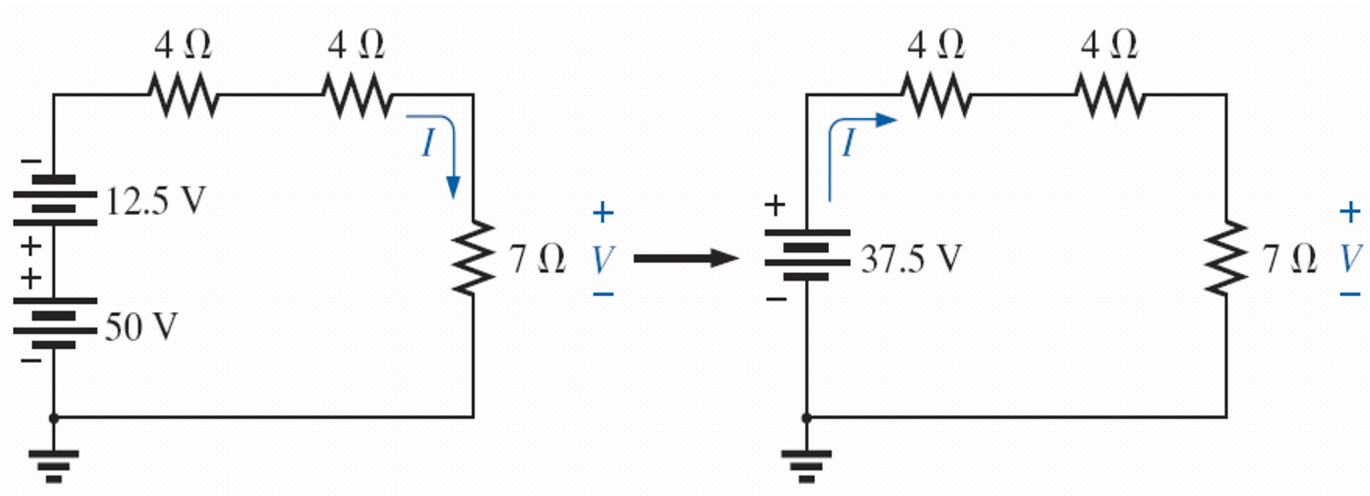


FIG. 5.44 *Redrawing the circuit in Fig. 5.43.*

NOTATION

Voltage Sources and Ground

- Except for a few special cases, electrical and electronic systems are grounded for reference and safety purposes.

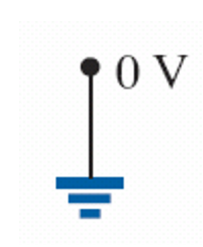


FIG. 5.45
*Ground
potential.*

NOTATION

Voltage Sources and Ground

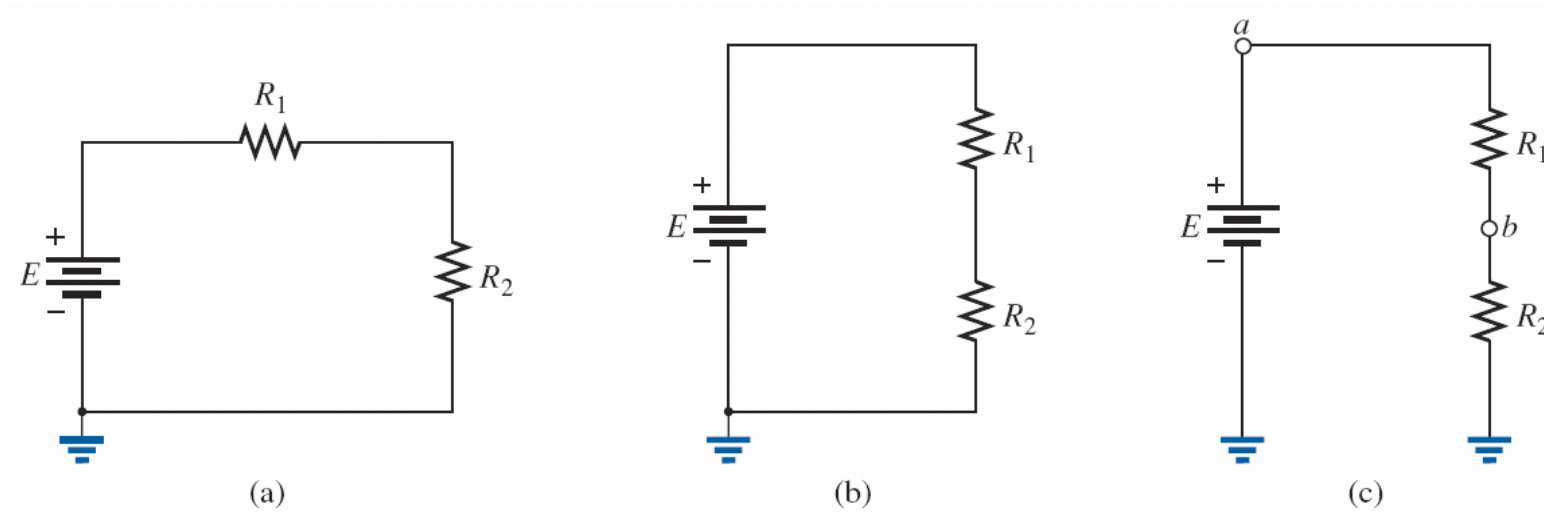


FIG. 5.46 *Three ways to sketch the same series dc circuit.*

NOTATION

Voltage Sources and Ground

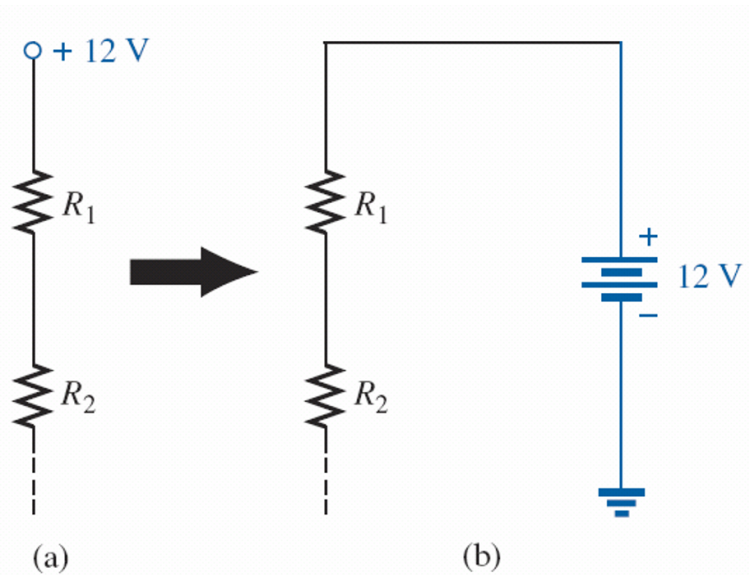


FIG. 5.47 Replacing the special notation for a dc voltage source with the standard symbol.

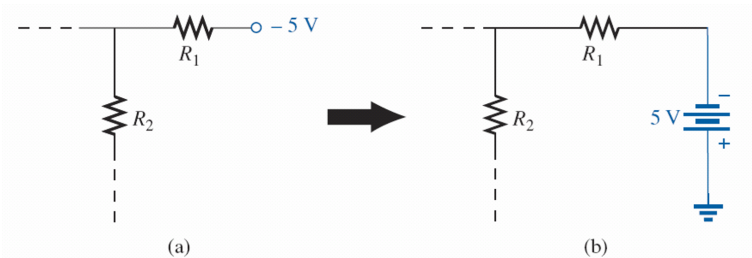


FIG. 5.48 Replacing the notation for a negative dc supply with the standard notation.

NOTATION

Voltage Sources and Ground

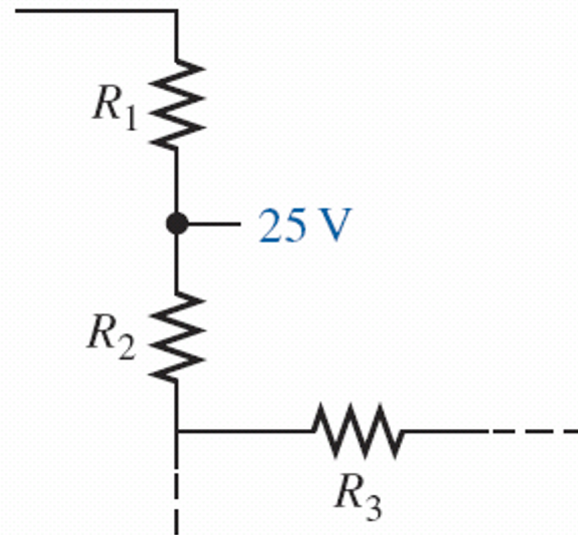


FIG. 5.49 *The expected voltage level at a particular point in a network if the system is functioning properly.*

NOTATION

Double-Subscript Notation

- The fact that voltage is an across variable and exists between two points has resulted in a double-subscript notation that defines the first subscript as

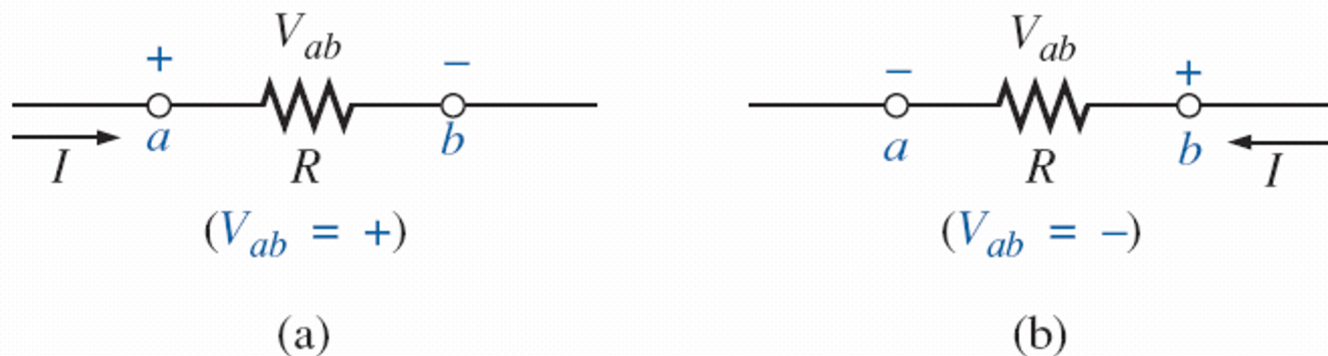


FIG. 5.50 *Defining the sign for double-subscript notation.*

NOTATION

Double-Subscript Notation

- The double-subscript notation V_{ab} specifies point a as the higher potential.
- If this is not the case, a negative sign must be associated with the magnitude of V_{ab} .
- In other words, the voltage V_{ab} is the voltage at point a with respect to (w.r.t.) point b.

NOTATION

Single-Subscript Notation

- If point b of the notation V_{ab} is specified as ground potential (zero volts), then a single-subscript notation can be used that provides the voltage at a point with respect to ground.

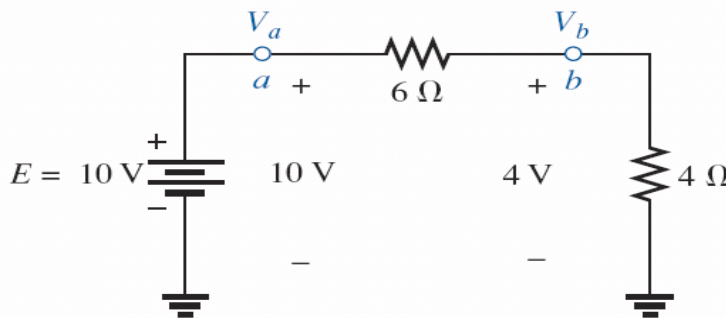


FIG. 5.51 *Defining the use of single-subscript notation for voltage levels.*

NOTATION

General Comments

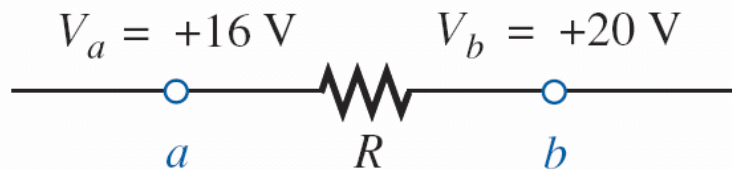


FIG. 5.52
Example
5.22.

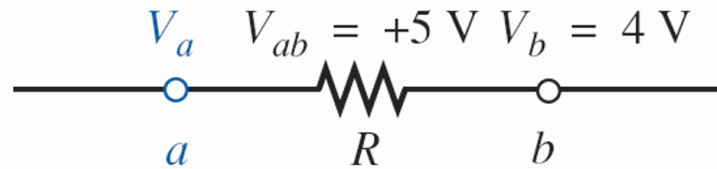


FIG. 5.53
Example
5.23.

NOTATION

General Comments

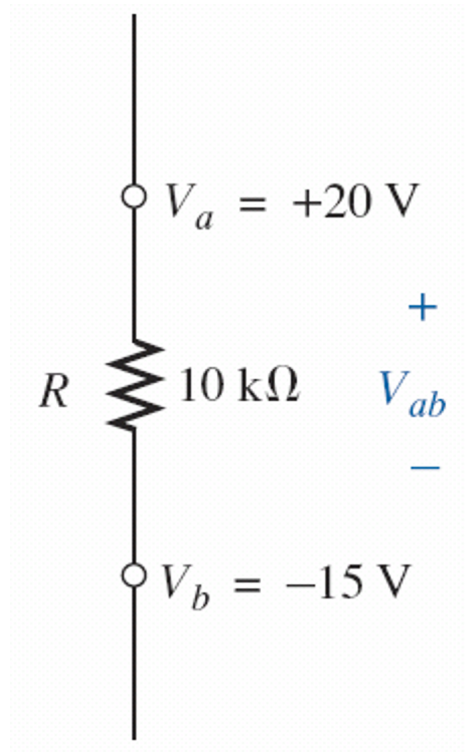


FIG. 5.54
Example 5.24.

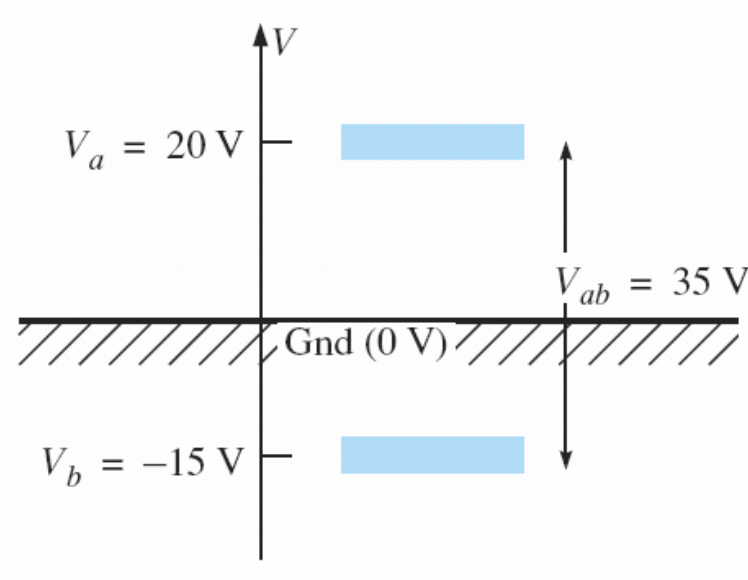


FIG. 5.55 *The impact of positive and negative voltages on the total voltage drop.*

NOTATION

General Comments

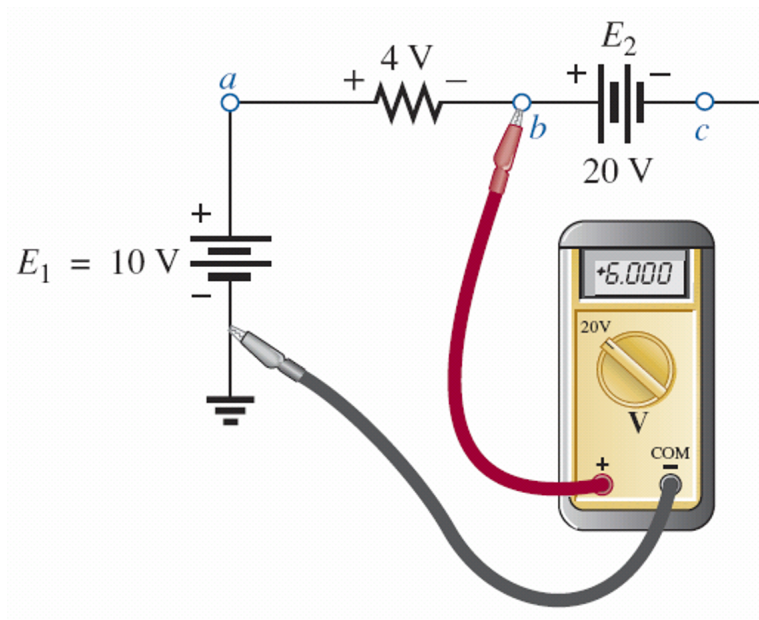


FIG. 5.56
Example 5.25.

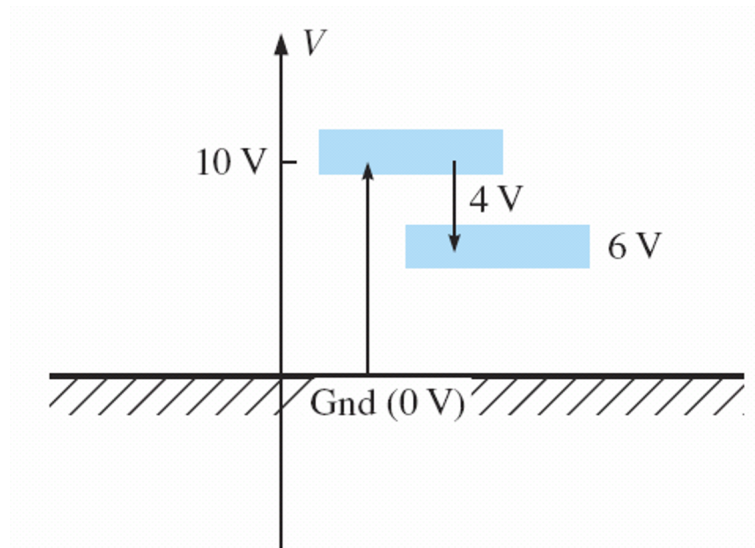


FIG. 5.57 *Determining V_b using the defined voltage levels.*

NOTATION

General Comments

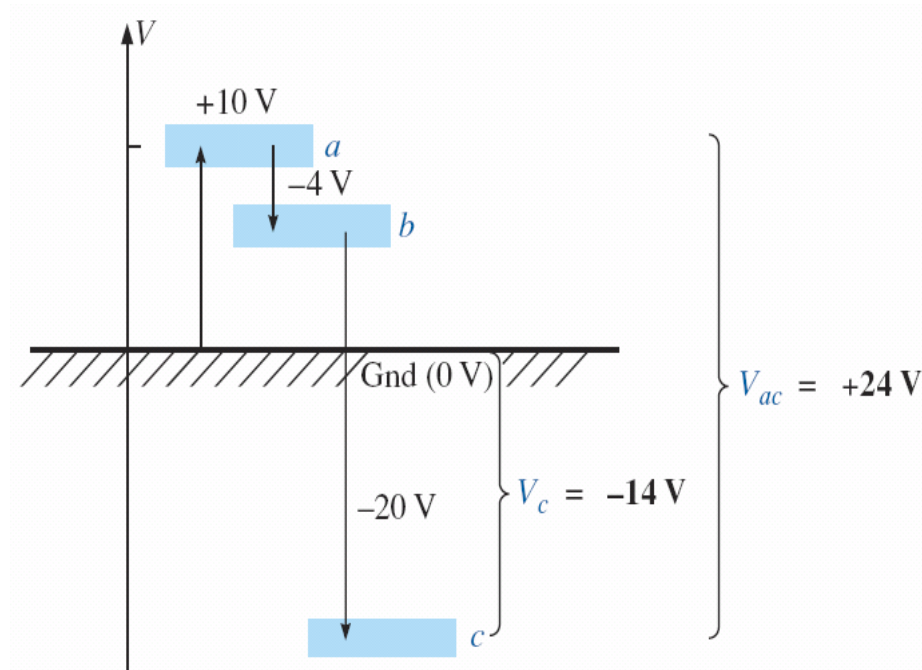


FIG. 5.58 *Review of the potential levels for the circuit in Fig. 5.56.*

NOTATION

General Comments

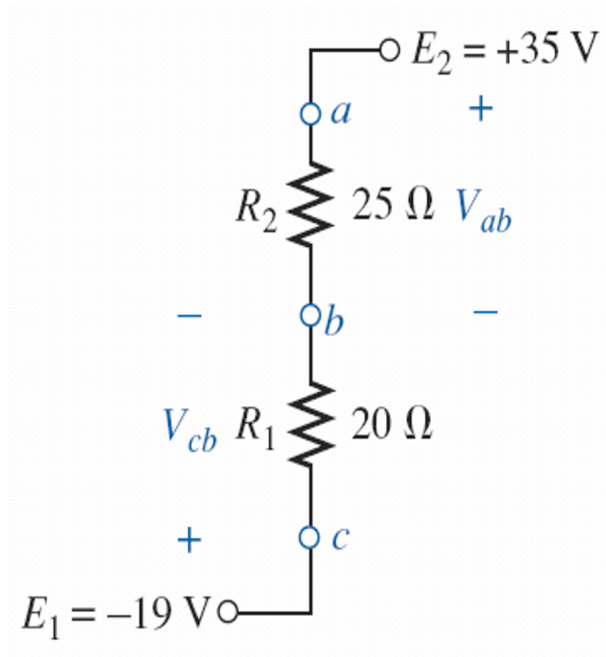


FIG. 5.59
Example
5.26.

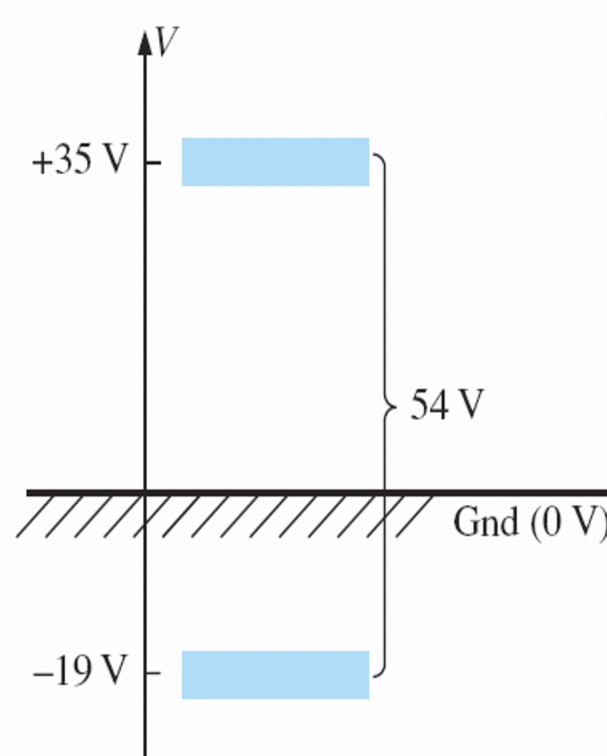


FIG. 5.60 *Determining the total voltage drop across the resistive elements in Fig 5.59.*

NOTATION

General Comments

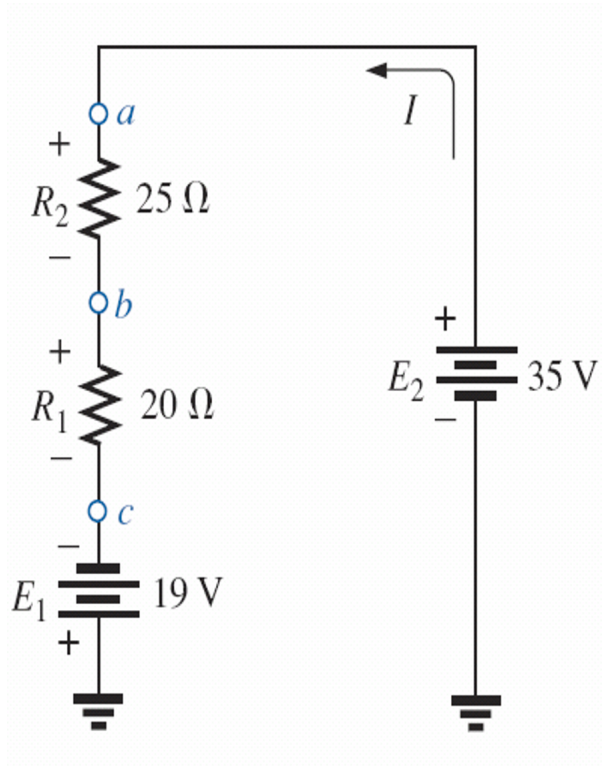


FIG. 5.61 Redrawing the circuit in Fig. 5.59 using standard dc voltage supply symbols.

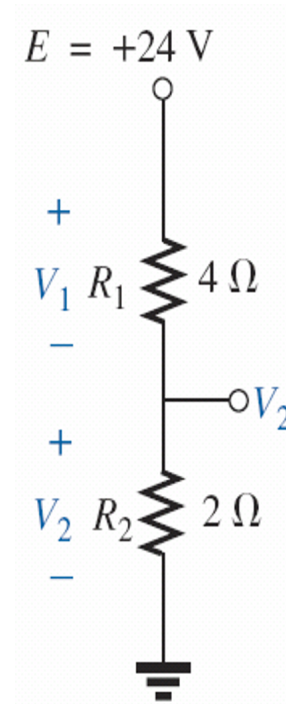


FIG. 5.62
Example 5.27.

NOTATION

General Comments

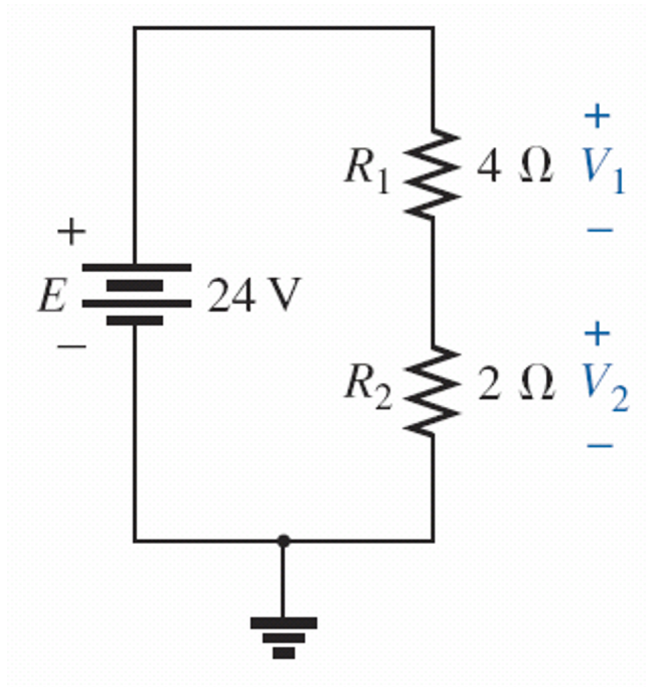


FIG. 5.63 *Circuit of Fig. 5.62 redrawn.*

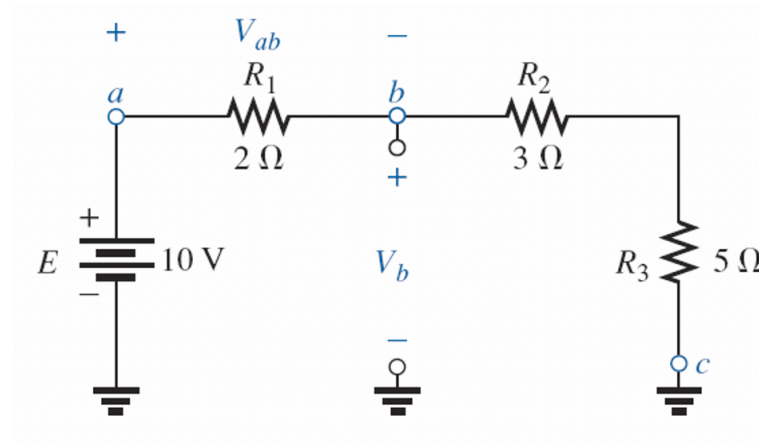


FIG. 5.64
Example 5.28.

GROUND CONNECTION AWARENESS

- The placement of the ground connection will not affect the magnitude or polarity of the voltage across an element but it may have a significant impact on the voltage from any point in the network to ground.

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

- When you use a dc supply such as the generator, battery, or supply you initially assume that it will provide the desired voltage for any resistive load you may hook up to the supply.

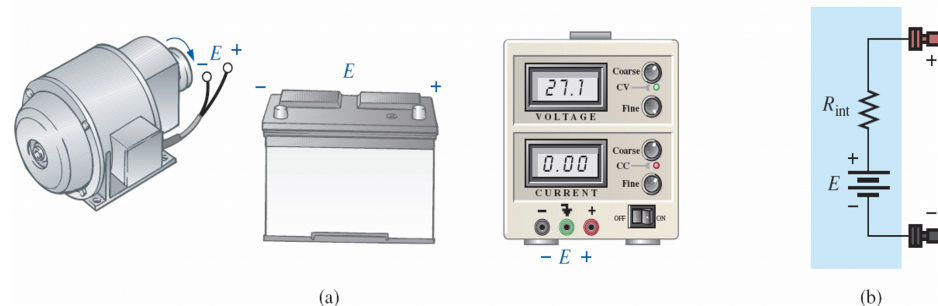


FIG. 5.68 (a) Sources of dc voltage;
(b) equivalent circuit.

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

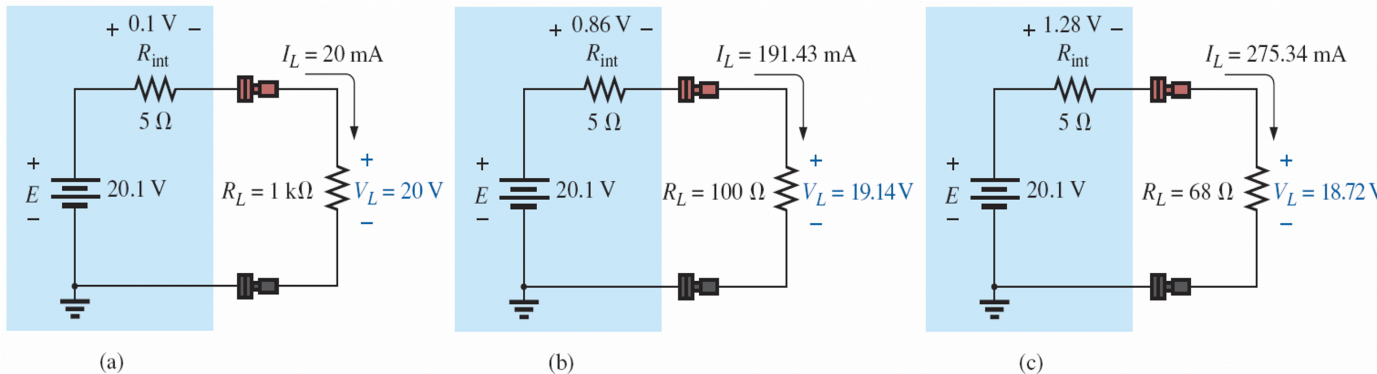


FIG. 5.69 *Demonstrating the effect of changing a load on the terminal voltage of a supply.*

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

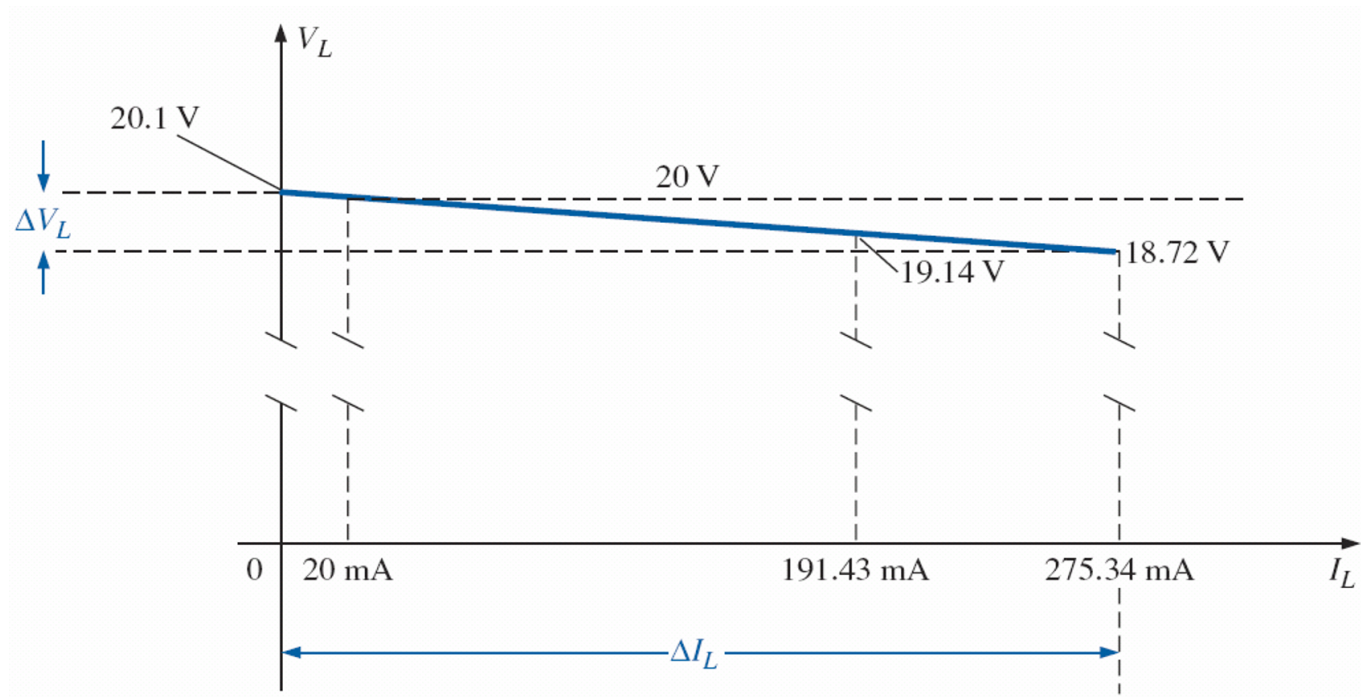


FIG. 5.70 Plotting V_L versus I_L for the supply in Fig. 5.69.

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

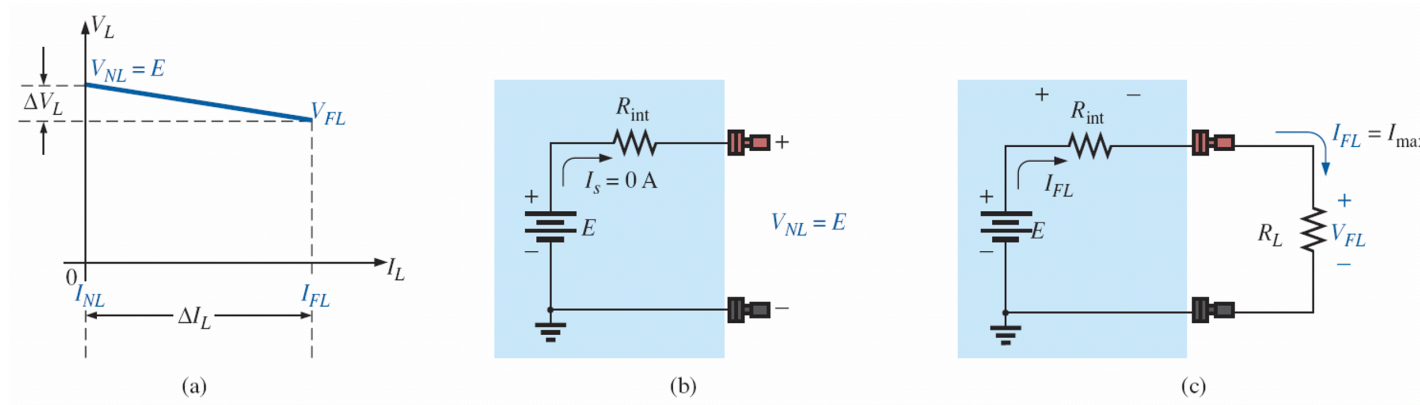


FIG. 5.71 *Defining the properties of importance for a power supply.*

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

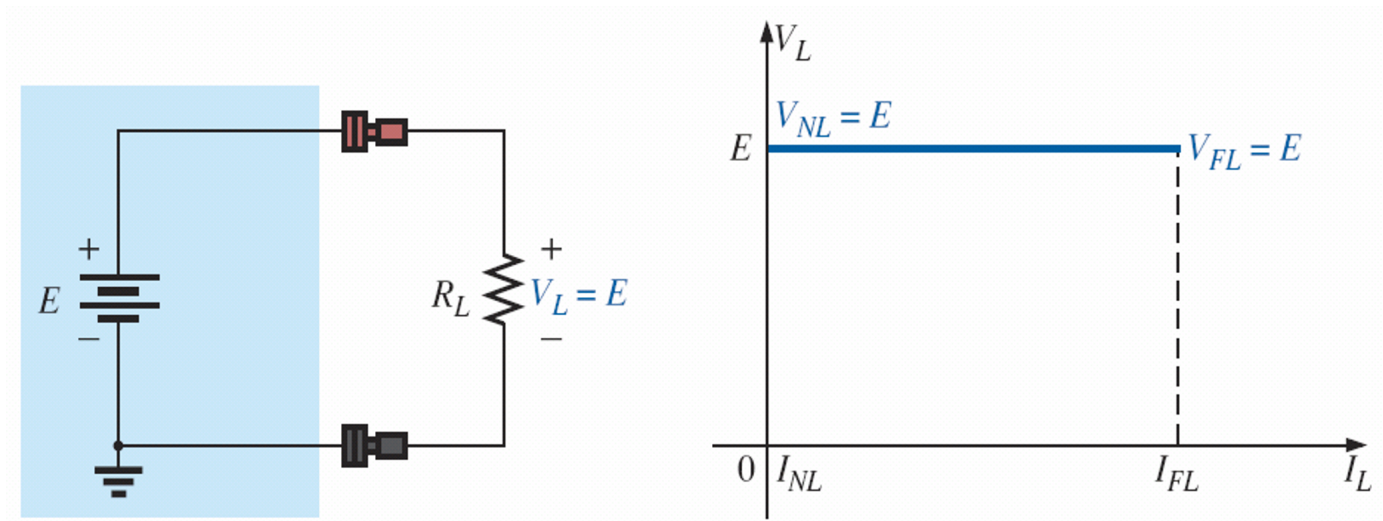


FIG. 5.72 *Ideal supply and its terminal characteristics.*

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

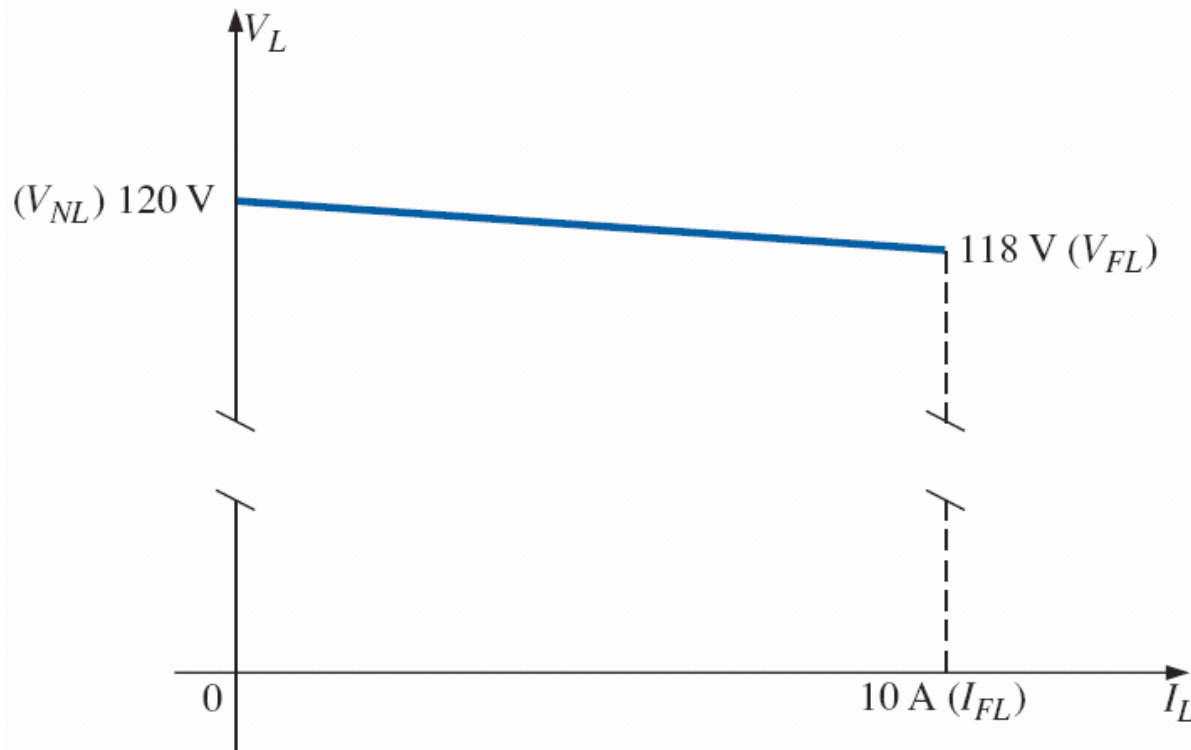


FIG. 5.73 *Terminal characteristics for the supply of Example 5.28.*

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

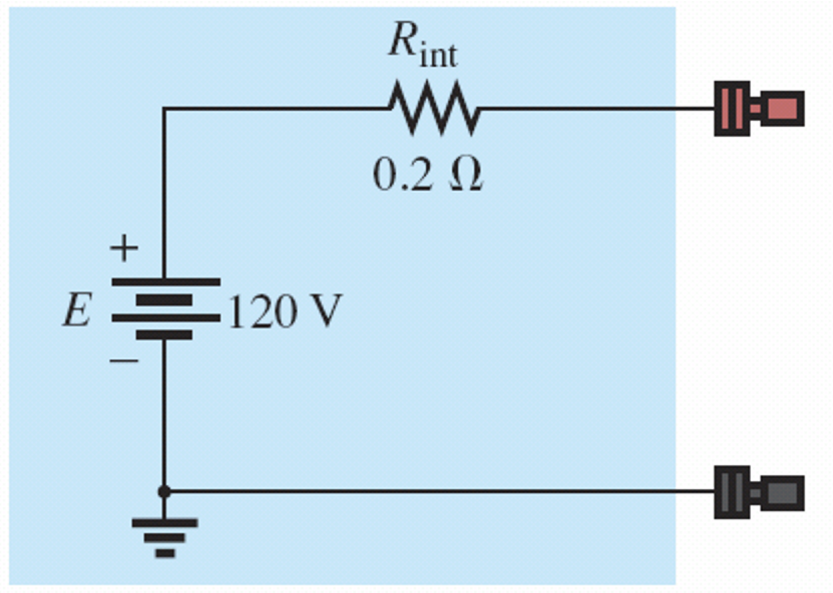


FIG. 5.74 *dc supply with the terminal characteristics of Fig. 5.73.*

VOLTAGE REGULATION & INTERNAL RESISTANCE OF VOLTAGE SOURCES

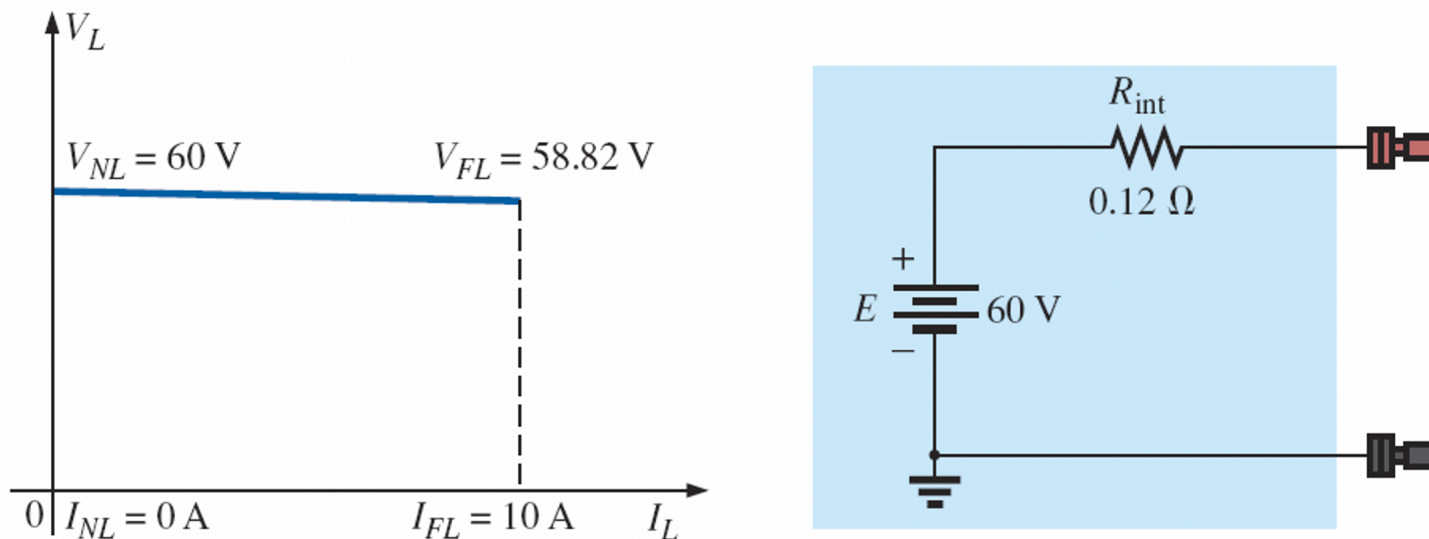


FIG. 5.75 *Characteristics and equivalent circuit for the supply of Example 5.33.*

LOADING EFFECTS OF INSTRUMENTS

- In the previous section, we learned that power supplies are not the ideal instruments we may have thought they were.
- The applied load can have an effect on the terminal voltage.

LOADING EFFECTS OF INSTRUMENTS

- Fortunately, since today's supplies have such small load regulation factors, the change in terminal voltage with load can usually be ignored for most applications.
- If we now turn our attention to the various meters we use in the lab, we again find that they are not totally ideal:

LOADING EFFECTS OF INSTRUMENTS

- Whenever you apply a meter to a circuit, you change the circuit and the response of the system. Fortunately, however, for most applications, considering the meters to be ideal is a valid approximation as long as certain factors are considered.

LOADING EFFECTS OF INSTRUMENTS

- For instance, any ammeter connected in a series circuit will introduce resistance to the series combination that will affect the current and voltages of the configuration.
- The resistance between the terminals of an ammeter is determined by the chosen scale of the ammeter.

LOADING EFFECTS OF INSTRUMENTS

- In general, for ammeters, the higher the maximum value of the current for a particular scale, the smaller will the internal resistance be.

LOADING EFFECTS OF INSTRUMENTS

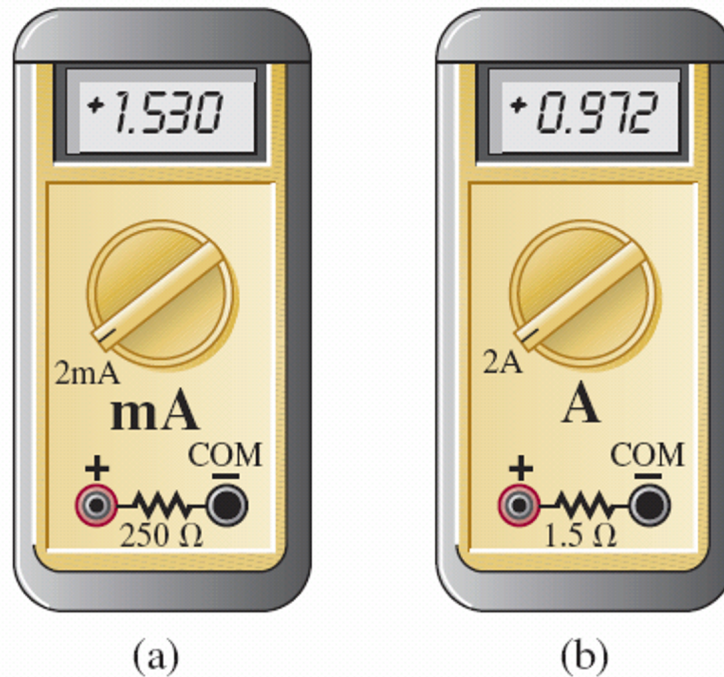


FIG. 5.76 Including the effects of the internal resistance of an ammeter: (a) 2 mA scale; (b) 2 A scale.

LOADING EFFECTS OF INSTRUMENTS

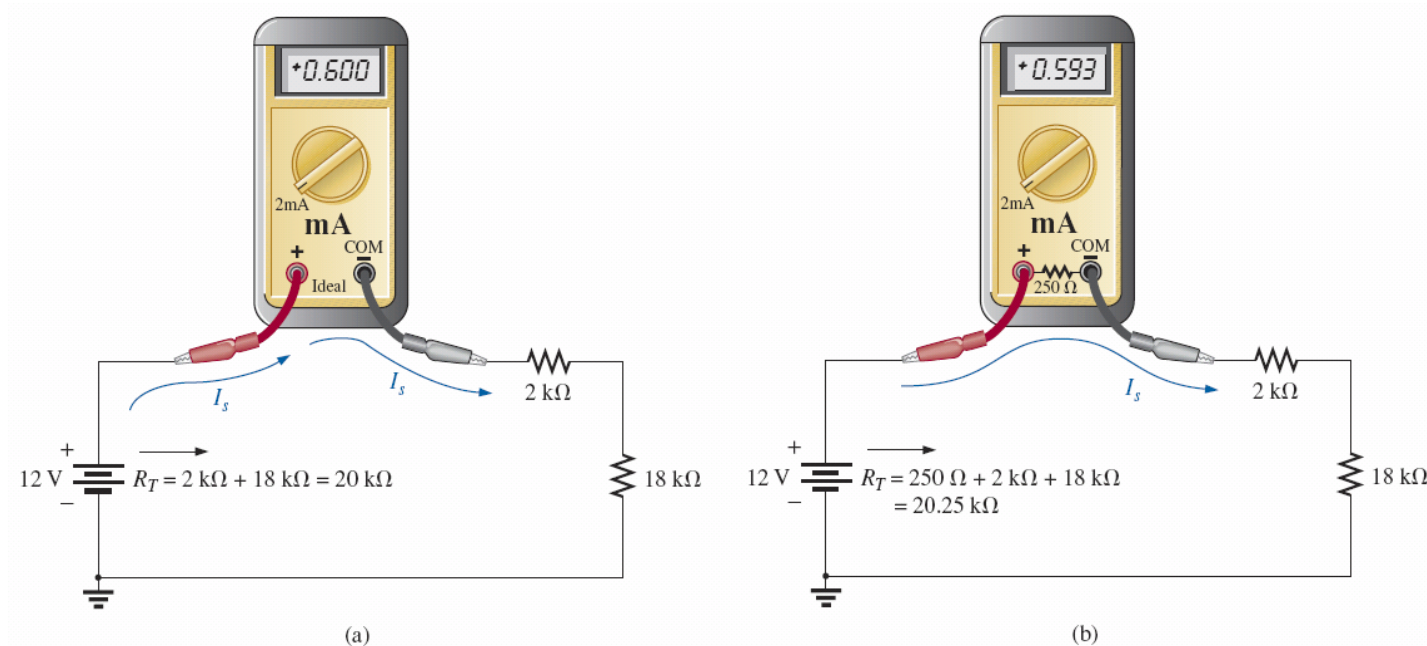


FIG. 5.77 Applying an ammeter set on the 2 mA scale to a circuit with resistors in the kilohm range: (a) ideal; (b) practical.

PROTOBOARDS (BREADBOARDS)

- At some point in the design of any electrical/electronic system, a prototype must be built and tested.
- One of the most effective ways to build a testing model is to use the protoboard (in the past most commonly called a breadboard).

PROTOBOARDS (BREADBOARDS)

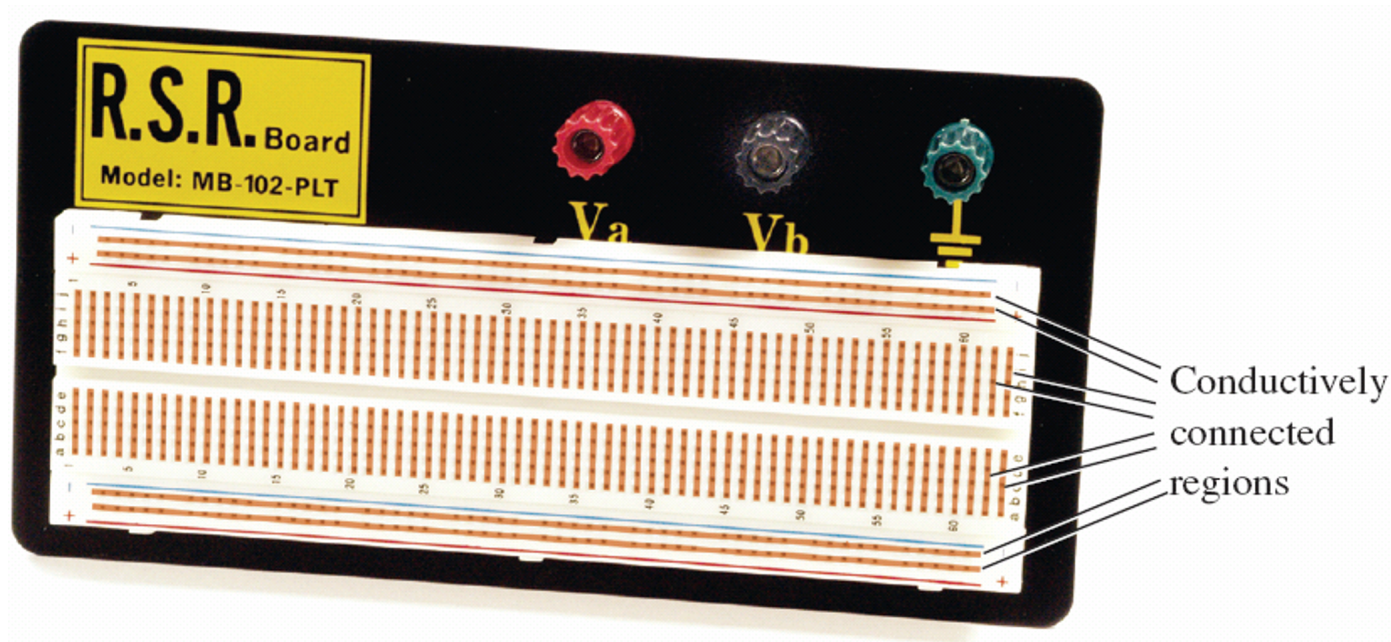


FIG. 5.78 *Protoboard with areas of conductivity defined using two different approaches.*

PROTOBOARDS (BREADBOARDS)

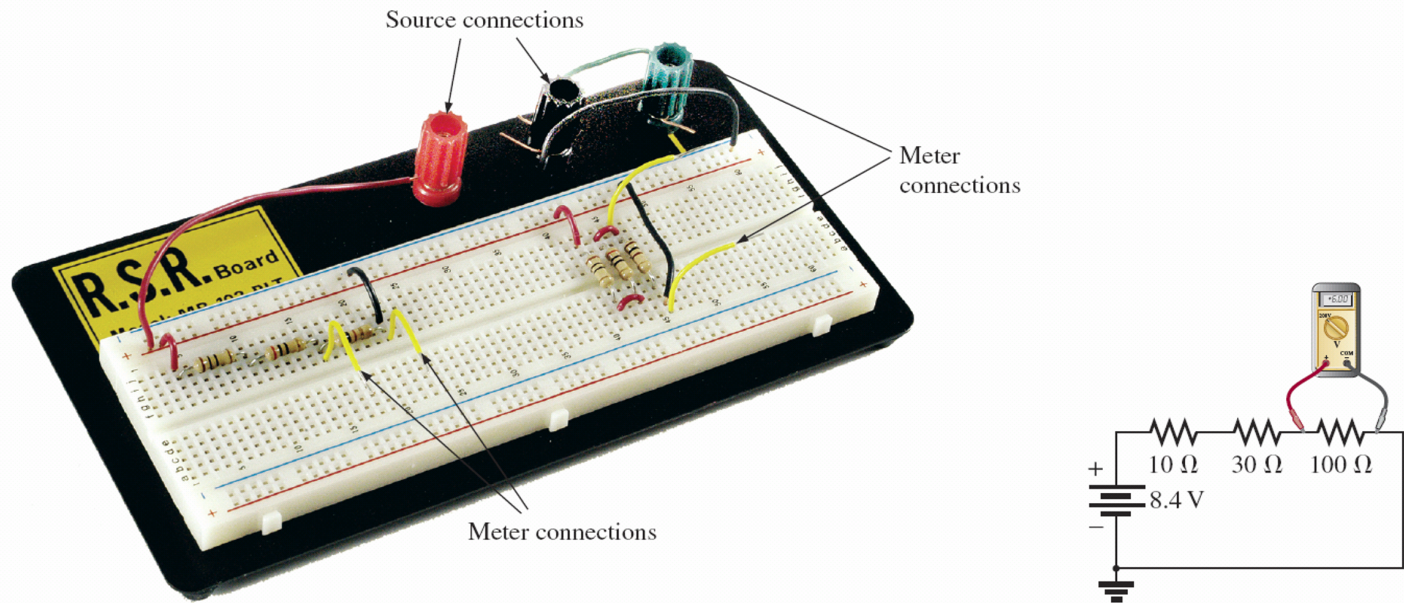


FIG. 5.79 Two setups for the network in Fig. 5.12 on a protoboard with yellow leads added to each configuration to measure voltage V_3 with a voltmeter.

APPLICATIONS

- Before looking at a few applications, we need to consider a few general characteristics of the series configuration that you should always keep in mind when designing a system.

APPLICATIONS

- First, and probably the most important, is that if one element of a series combination of elements should fail, it will disrupt the response of all the series elements. If an open circuit occurs, the current will be zero. If a short circuit results, the voltage will increase across the other elements, and the current will increase in magnitude.

APPLICATIONS

- Second, and a thought you should always keep in mind, is that for the same source voltage, the more elements you place in series, the less is the current and the less is the voltage across all the elements of the series combination.

APPLICATIONS

- Last, and a result discussed in detail in this chapter, is that the current is the same for each element of a series combination, but the voltage across each element is a function of its terminal resistance.

APPLICATIONS

Series Control

- One common use of the series configuration is in setting up a system that ensures that everything is in place before full power is applied.

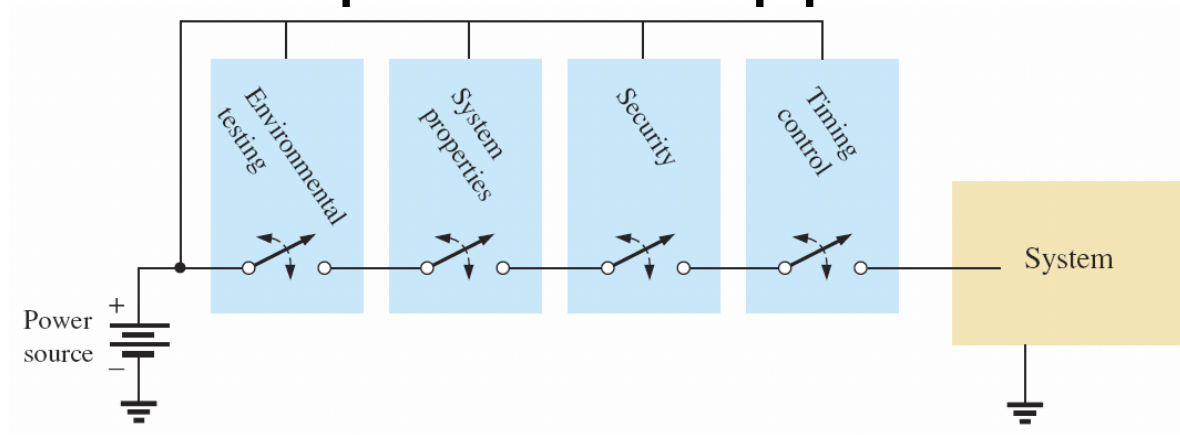


FIG. 5.80 *Series control over an operating system.*

APPLICATIONS

Holiday Lights

- In recent years, the small blinking holiday lights with 50 to 100 bulbs on a string have become very popular.

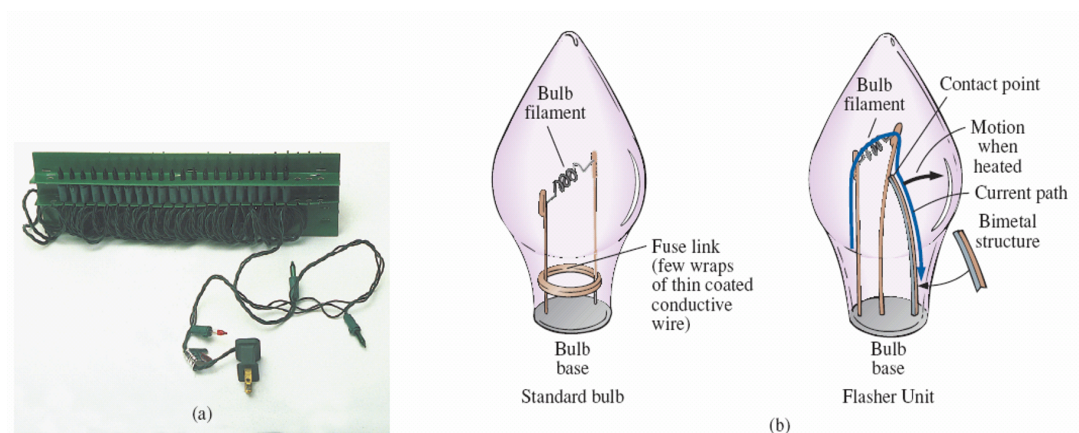


FIG. 5.81 *Holiday lights: (a) 50-unit set; (b) bulb construction.*

APPLICATIONS

Holiday Lights

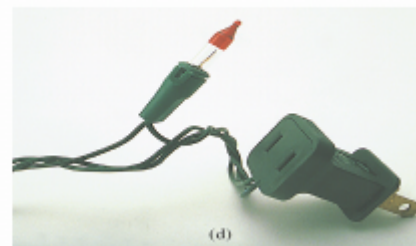
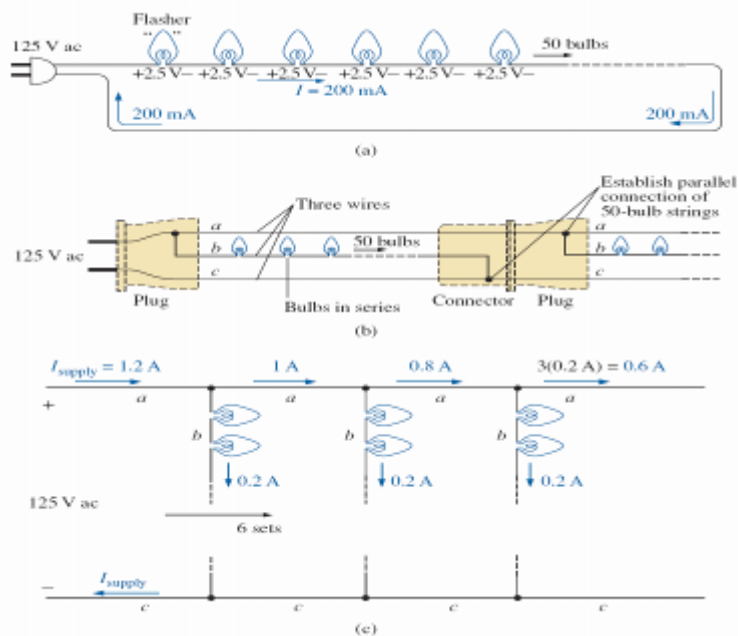


FIG. 5.82 (a) Single-set wiring diagram; (b) special wiring arrangement; (c) redrawn schematic; (d) special plug and flasher unit.

APPLICATIONS

Microwave Oven

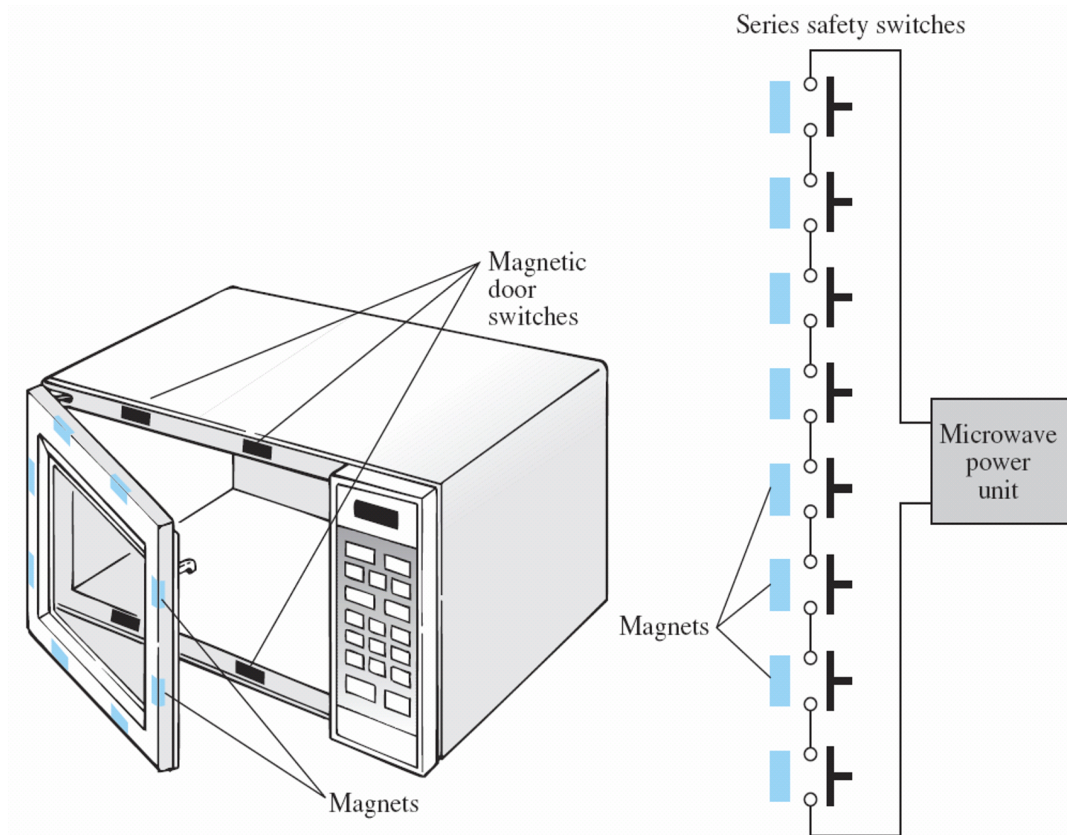


FIG. 5.83 *Series safety switches in a microwave oven.*

APPLICATIONS

Series Alarm Circuit

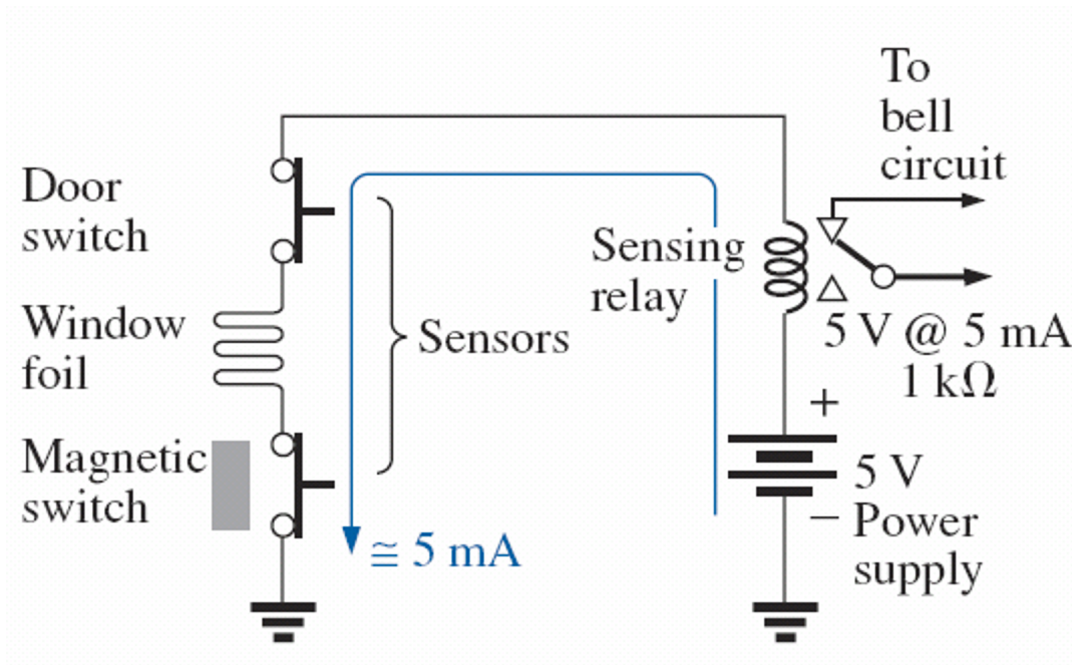


FIG. 5.84 *Series alarm circuit.*

COMPUTER ANALYSIS

PSpice

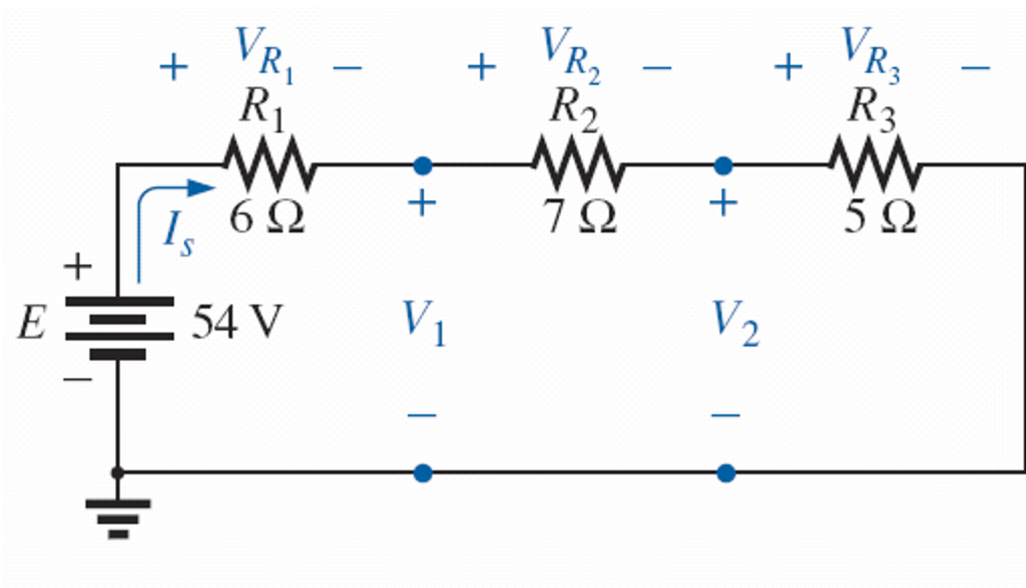


FIG. 5.85 Series dc network to be analyzed using PSpice.

COMPUTER ANALYSIS

PSpice

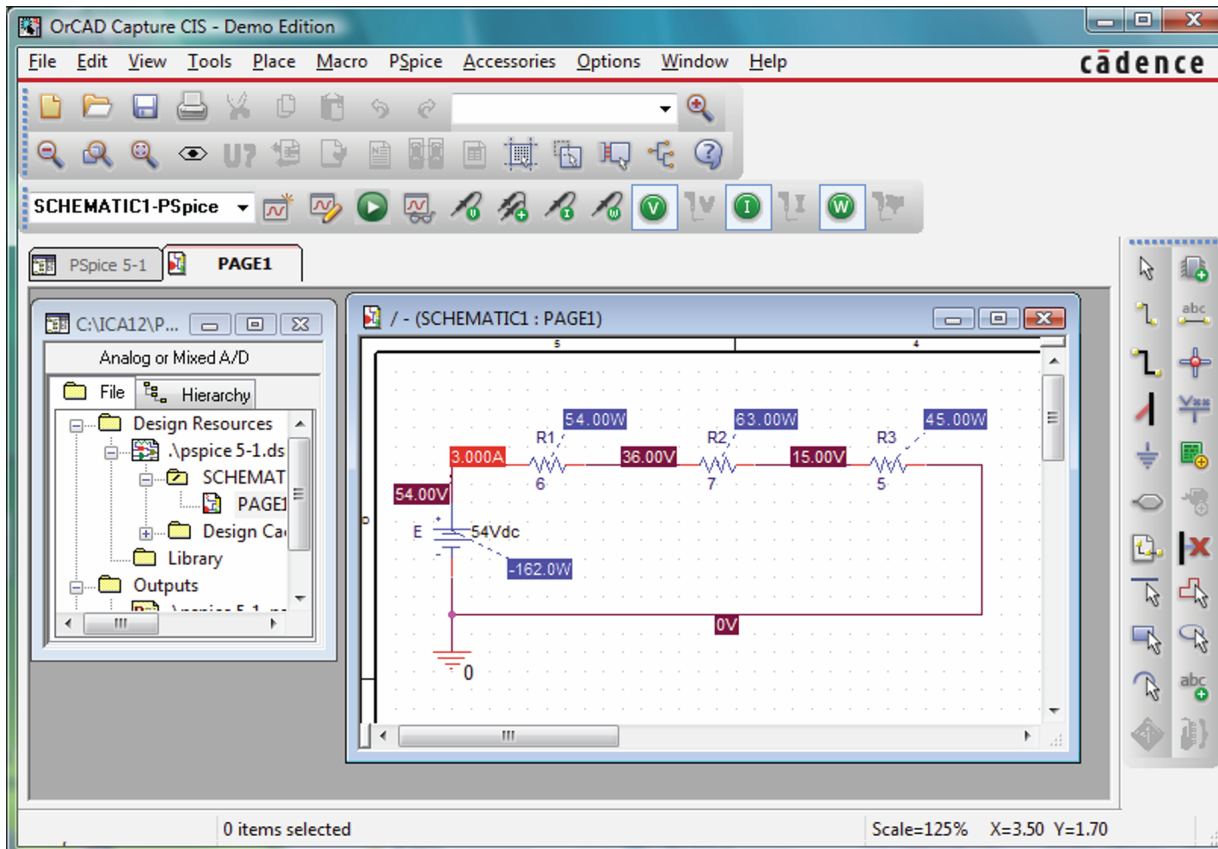


FIG. 5.86 *Applying PSpice to a series dc circuit.*

COMPUTER ANALYSIS

Multisim

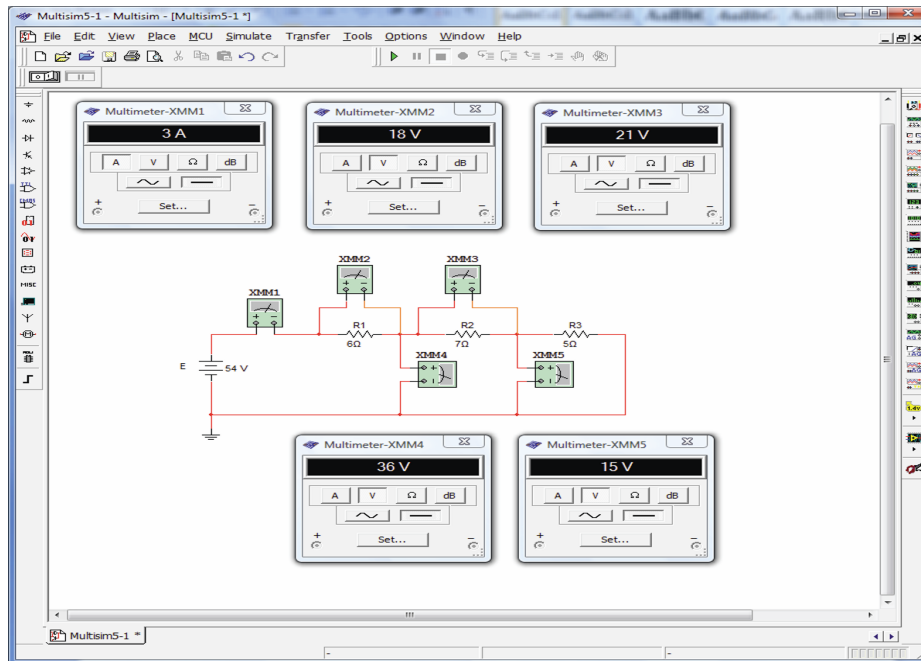
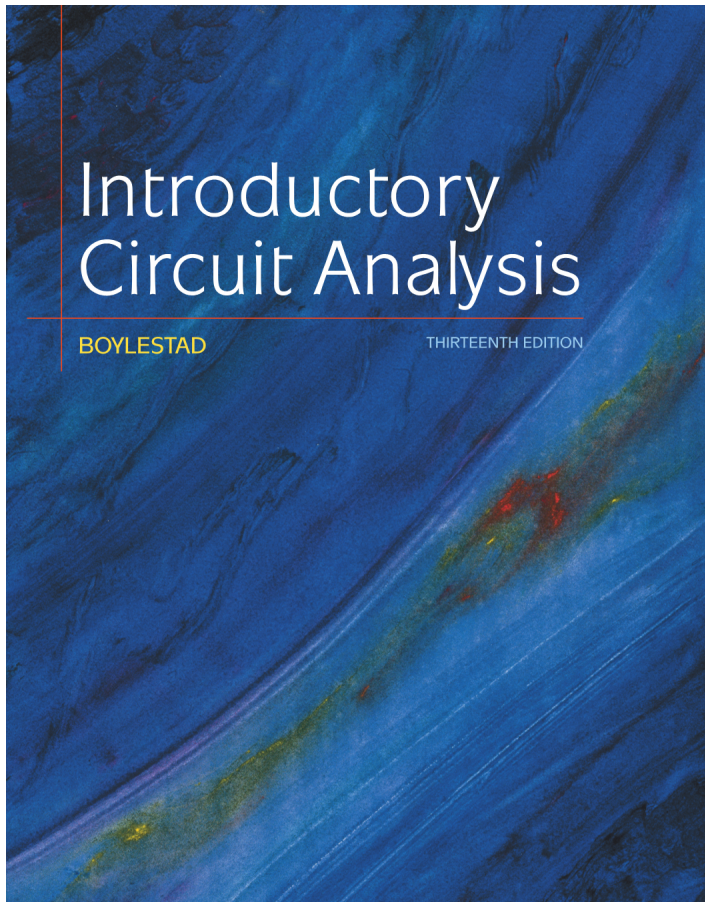


FIG. 5.87
*Applying
Multisim to a
series dc circuit.*

Introductory Circuit Analysis



CHAPTER 6

Parallel dc Circuits

OBJECTIVES

- Become familiar with the characteristics of a parallel network and how to solve for the voltage, current, and power to each element.
- Develop a clear understanding of Kirchhoff's current law and its importance to the analysis of electric circuits.

OBJECTIVES

- Become aware of how the source current will split between parallel elements and how to properly apply the current divider rule.
- Clearly understand the impact of open and short circuits on the behavior of a network.

OBJECTIVES

- Learn how to use an ohmmeter, voltmeter, and ammeter to measure the important parameters of a parallel network.

INTRODUCTION

- Two network configurations, series and parallel, form the framework for some of the most complex network structures.
- A clear understanding of each will pay enormous dividends as more complex methods and networks are examined.

PARALLEL RESISTORS

- The term parallel is used so often to describe a physical arrangement between two elements that most individuals are aware of its general characteristics.
 - In general, two elements, branches, or circuits are in parallel if they have two points in common.

PARALLEL RESISTORS

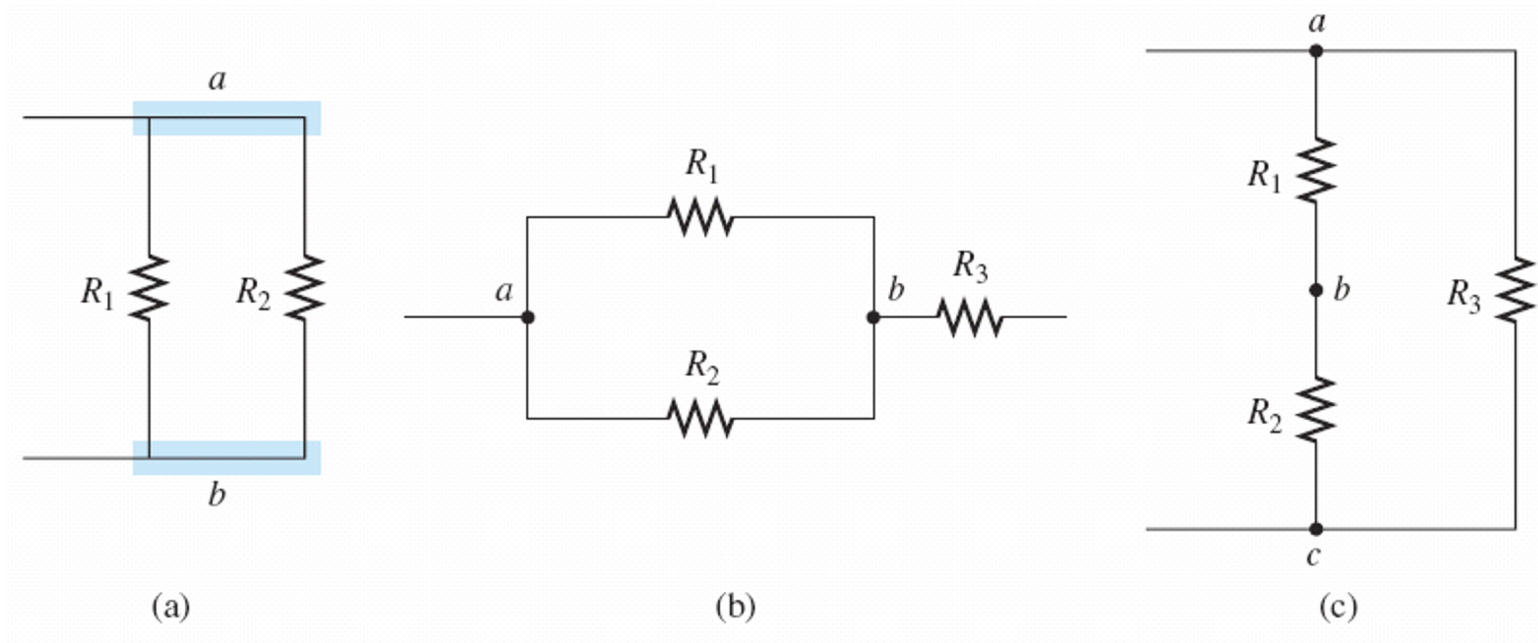


FIG. 6.1 (a) Parallel resistors; (b) R_1 and R_2 are in parallel; (c) R_3 is in parallel with the series combination of R_1 and R_2 .

PARALLEL RESISTORS

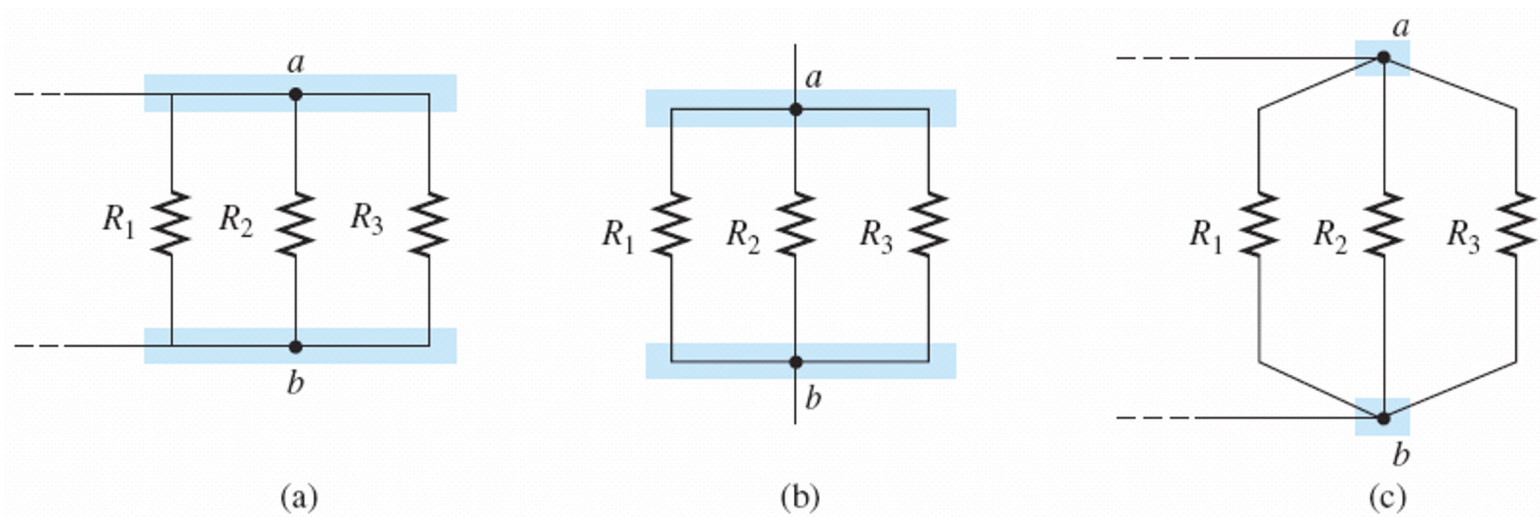


FIG. 6.2 *Schematic representations of three parallel resistors.*

PARALLEL RESISTORS

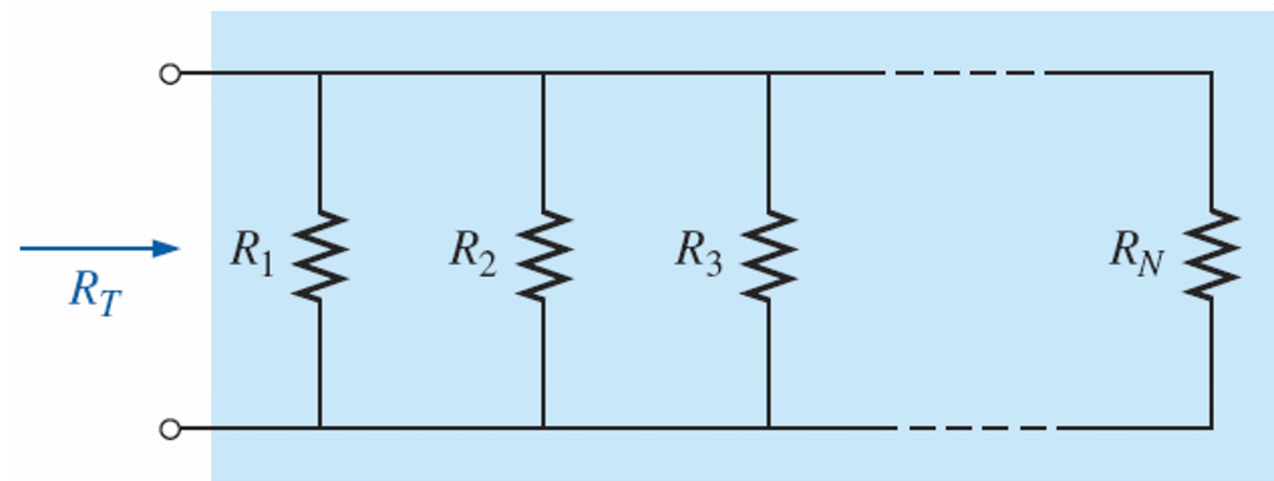


FIG. 6.3 *Parallel combination of resistors.*

PARALLEL RESISTORS

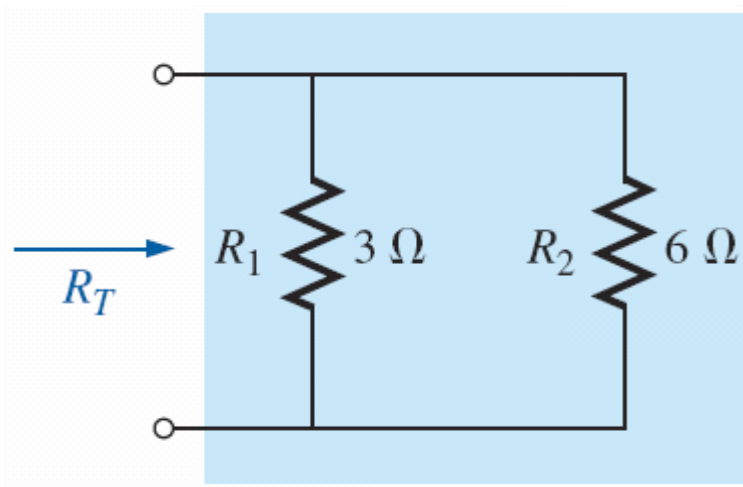


FIG. 6.4 *Parallel resistors for Example 6.1.*

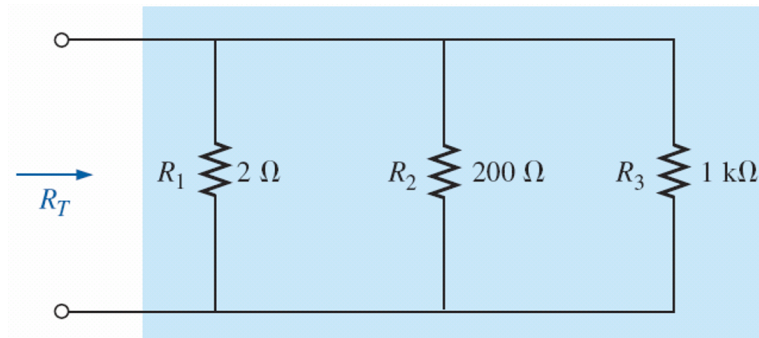


FIG. 6.5 *Parallel resistors for Example 6.2.*

PARALLEL RESISTORS

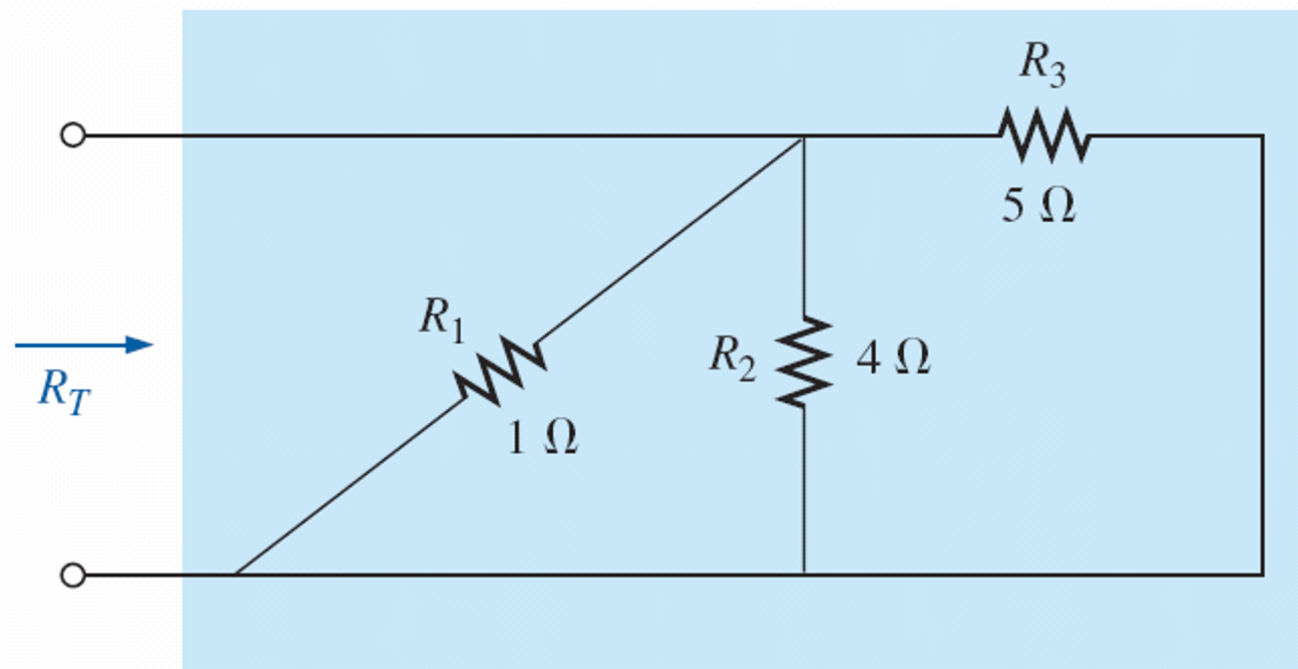


FIG. 6.6 *Network to be investigated in Example 6.3.*

PARALLEL RESISTORS

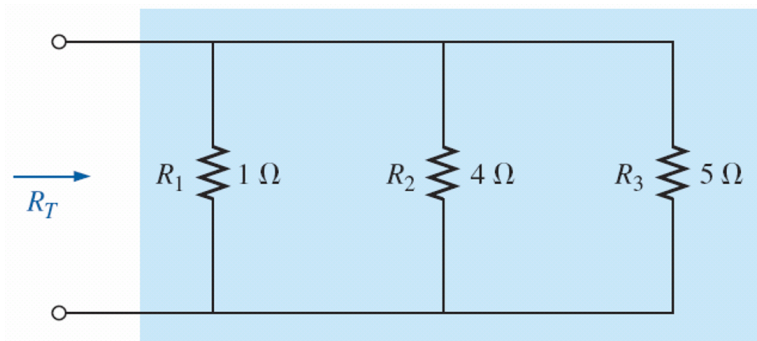


FIG. 6.7 Network in Fig. 6.6 redrawn.

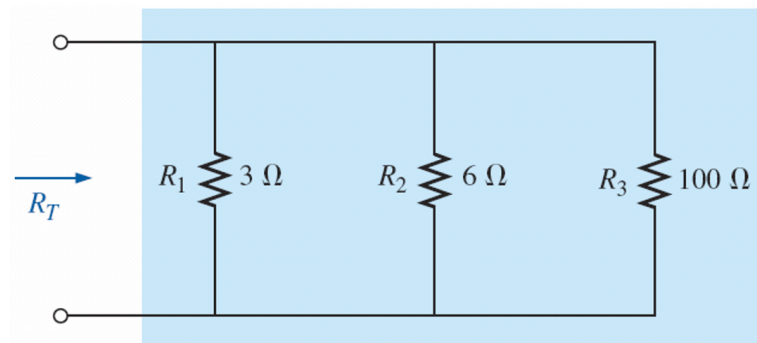


FIG. 6.8 Adding a parallel 100 resistor to the network in Fig. 6.4.

PARALLEL RESISTORS: Special Case- Equal Parallel Resistors

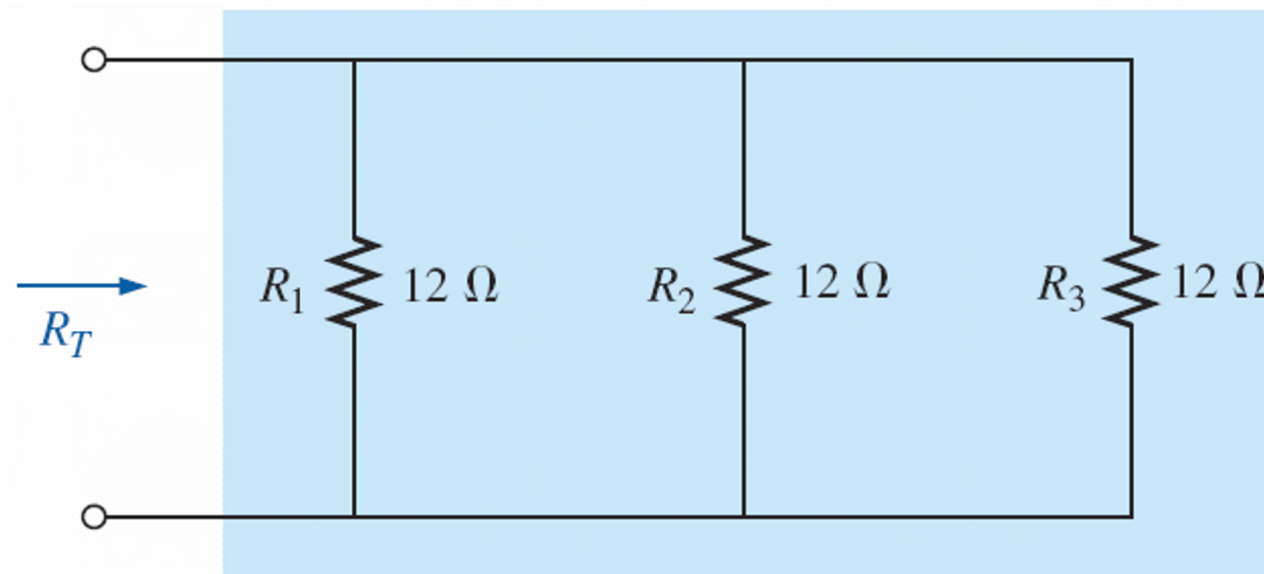


FIG. 6.9 *Three equal parallel resistors to be investigated in Example 6.5.*

PARALLEL RESISTORS: Special Case- Equal Parallel Resistors

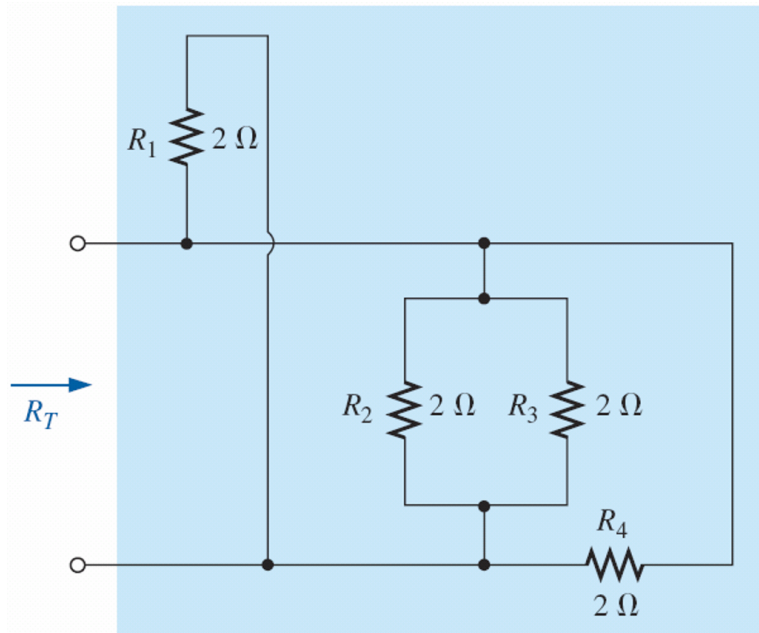


FIG. 6.10 *Parallel configuration for Example 6.6.*

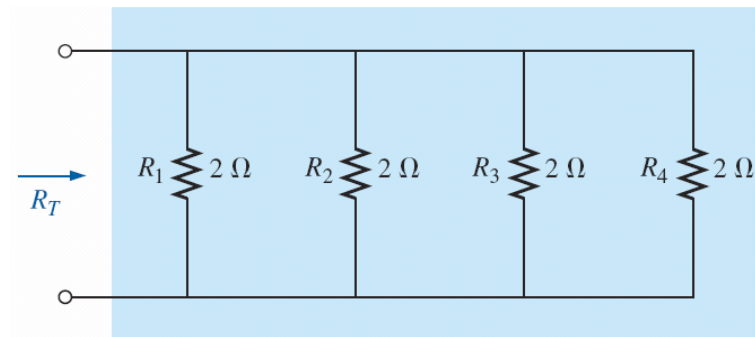


FIG. 6.11 *Network in Fig. 6.10 redrawn.*

PARALLEL RESISTORS: Special Case- Two Parallel Resistors

- In the vast majority of cases, only two or three parallel resistors will have to be combined.
- With this in mind, an equation has been derived for two parallel resistors that is easy to apply and removes the need to continually worry about dividing into 1 and possibly misplacing a decimal point.

PARALLEL RESISTORS: Special Case- Two Parallel Resistors

- For three parallel resistors, the equation to be derived here can be applied twice, or Eq. (6.3) can be used.

PARALLEL RESISTORS: Special Case- Two Parallel Resistors

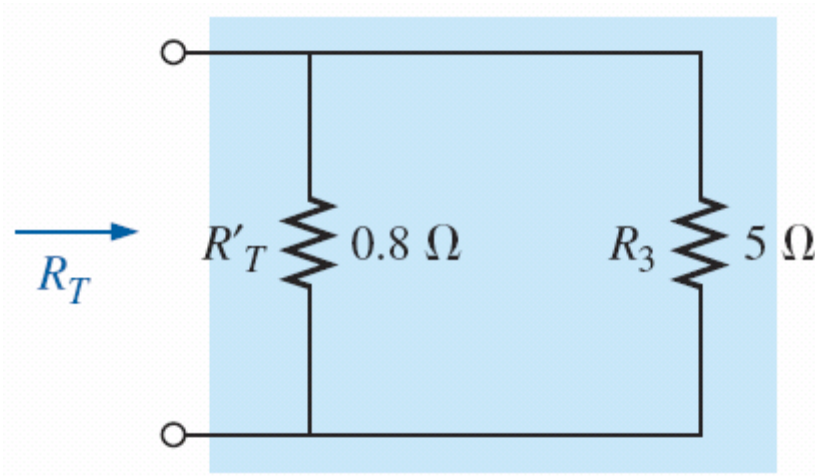


FIG. 6.12 *Reduced equivalent in Fig. 6.7.*

PARALLEL RESISTORS: Special Case- Two Parallel Resistors

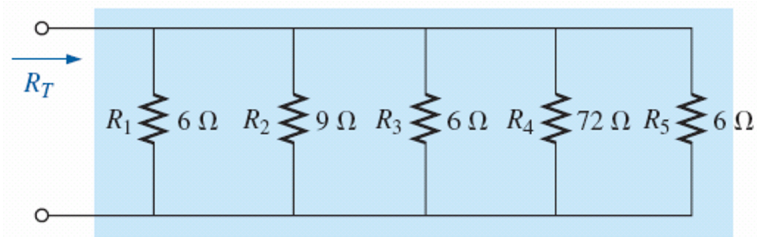


FIG. 6.13 *Parallel network for Example 6.9.*

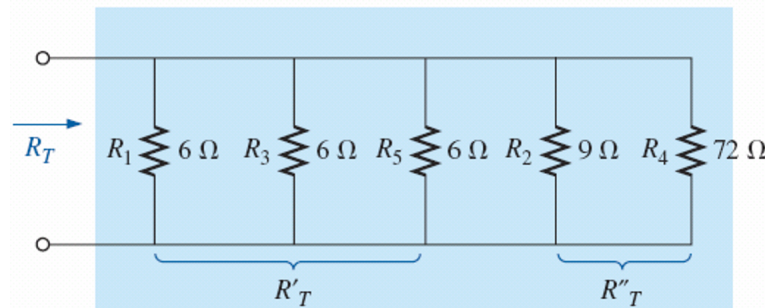


FIG. 6.14 *Redrawn network in Fig. 6.13 (Example 6.9).*

PARALLEL RESISTORS: Special Case- Two Parallel Resistors

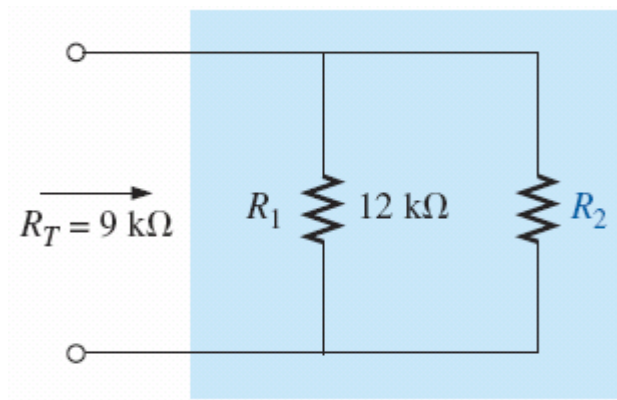


FIG. 6.15 *Parallel network for Example 6.10.*

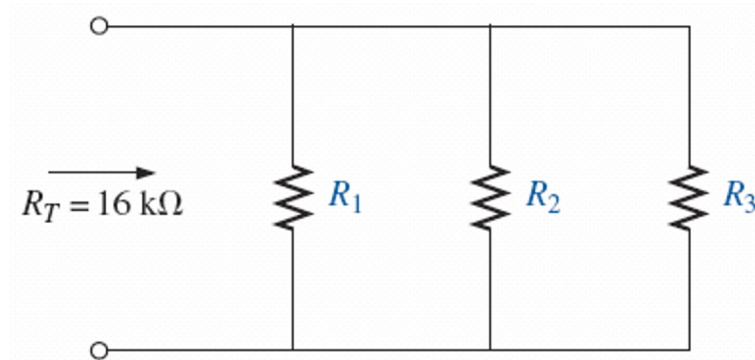


FIG. 6.16 *Parallel network for Example 6.11.*

PARALLEL RESISTORS

Analogies

- On a ladder, the rungs of the ladder form a parallel configuration.
- When ropes are tied between a grappling hook and a load, they effectively absorb the stress in a parallel configuration.
- The cables of a suspended roadway form a parallel configuration.

PARALLEL RESISTORS

Analogies

- There are numerous other analogies that demonstrate how connections between the same two points permit a distribution of stress between the parallel elements.

PARALLEL RESISTORS

Instrumentation

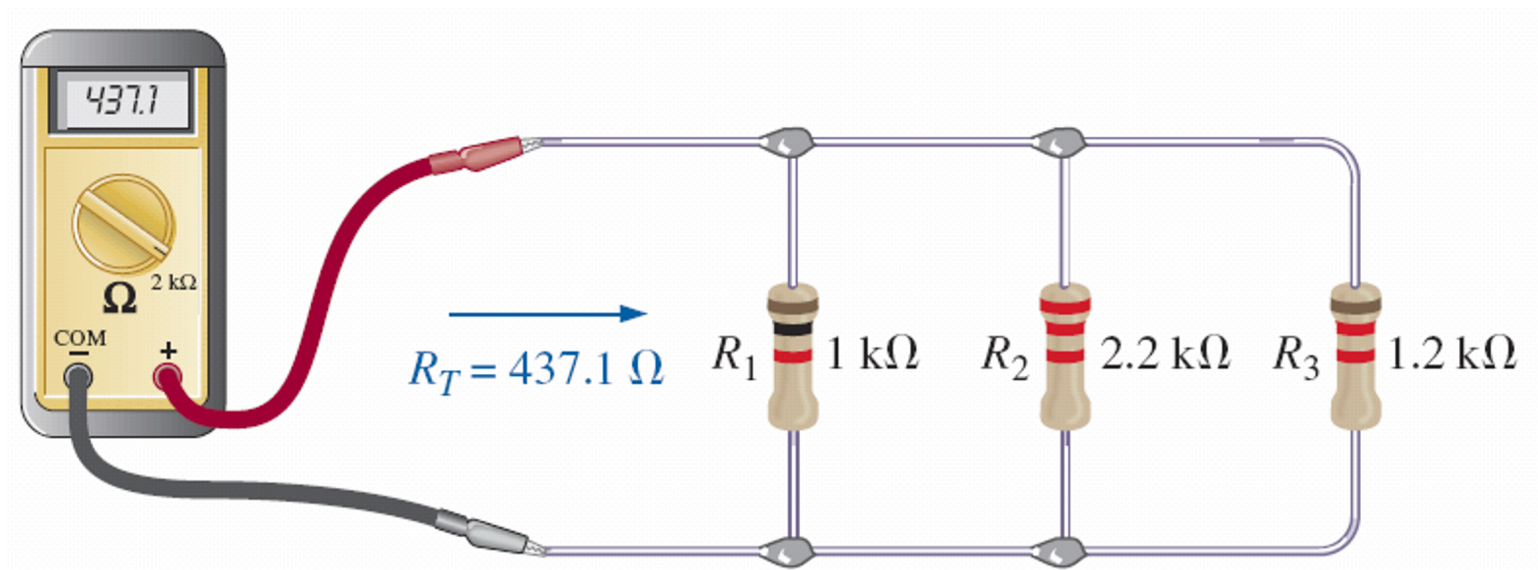


FIG. 6.17 *Using an ohmmeter to measure the total resistance of a parallel network.*

PARALLEL CIRCUITS

- A parallel circuit can now be established by connecting a supply across a set of parallel resistors as shown in Fig. 6.18.
- The positive terminal of the supply is directly connected to the top of each resistor, while the negative terminal is connected to the bottom of each resistor.

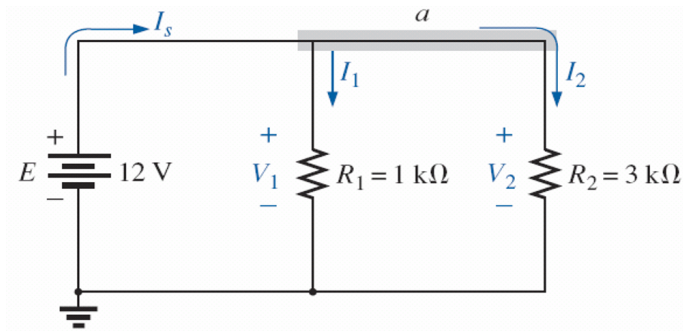


FIG. 6.18
Parallel network.

PARALLEL CIRCUITS

- In general, the voltage is always the same across parallel elements.
 - Therefore, remember that if two elements are in parallel, the voltage across them must be the same. However, if the voltage across two neighboring elements is the same, the two elements may or may not be in parallel.

PARALLEL CIRCUITS

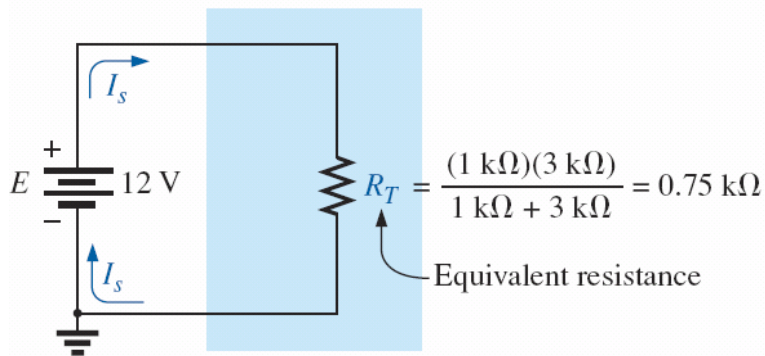


FIG. 6.19 Replacing the parallel resistors in Fig. 6.18 with the equivalent total resistance.

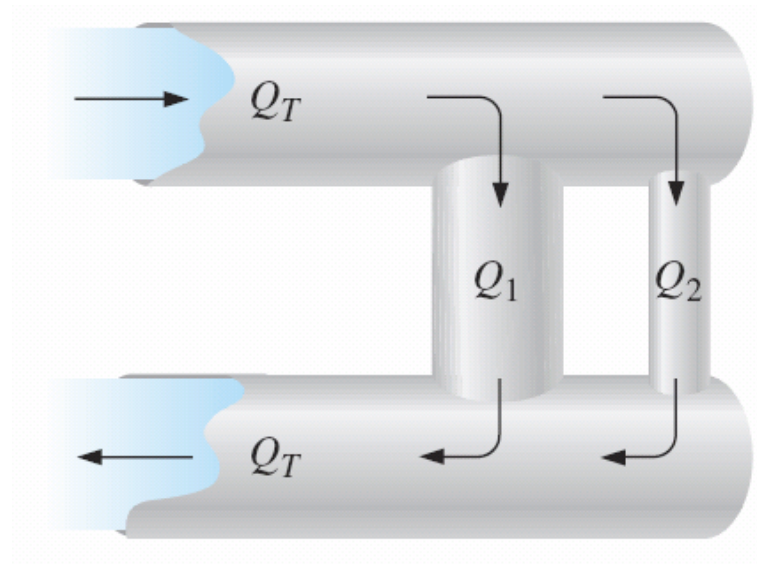


FIG. 6.20
Mechanical analogy for Fig. 6.18.

PARALLEL CIRCUITS

- For single-source parallel networks, the source current (I_s) is always equal to the sum of the individual branch currents.

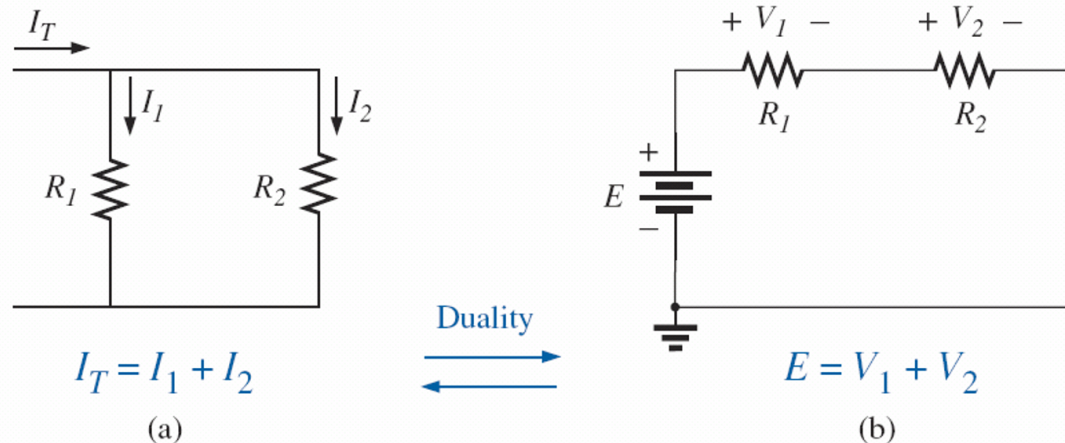


FIG. 6.21 *Demonstrating the duality that exists between series and parallel circuits.*

PARALLEL CIRCUITS

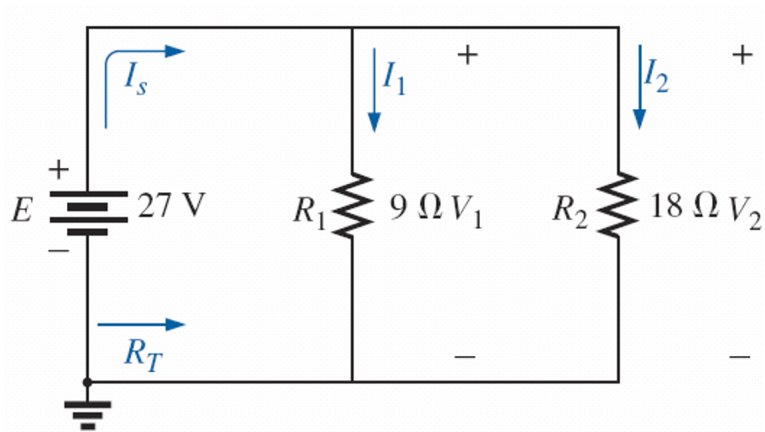


FIG. 6.22 *Parallel network for Example 6.12.*

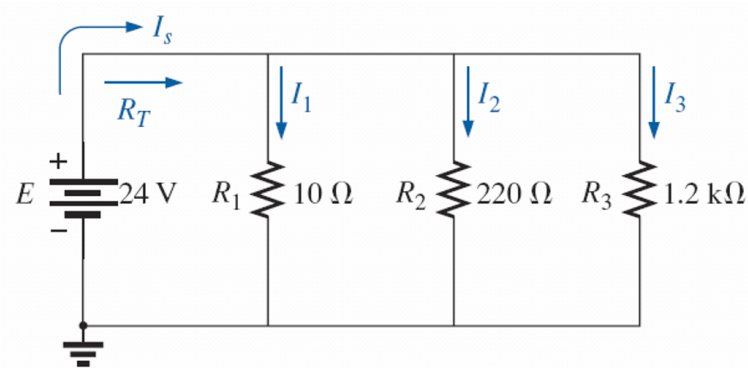


FIG. 6.23 *Parallel network for Example 6.13.*

PARALLEL CIRCUITS

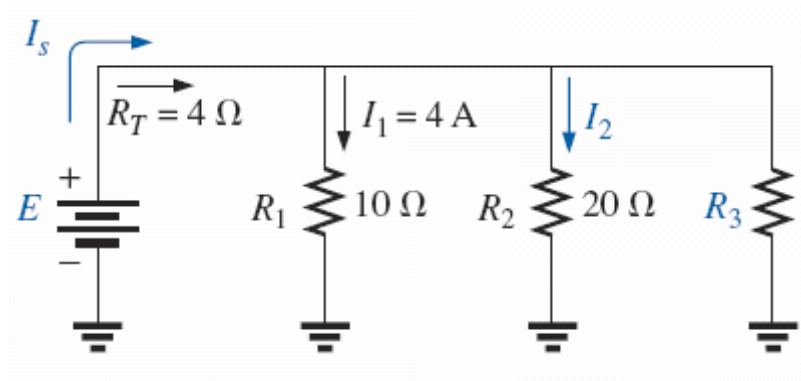


FIG. 6.24 *Parallel network for Example 6.14.*

PARALLEL CIRCUITS

Instrumentation

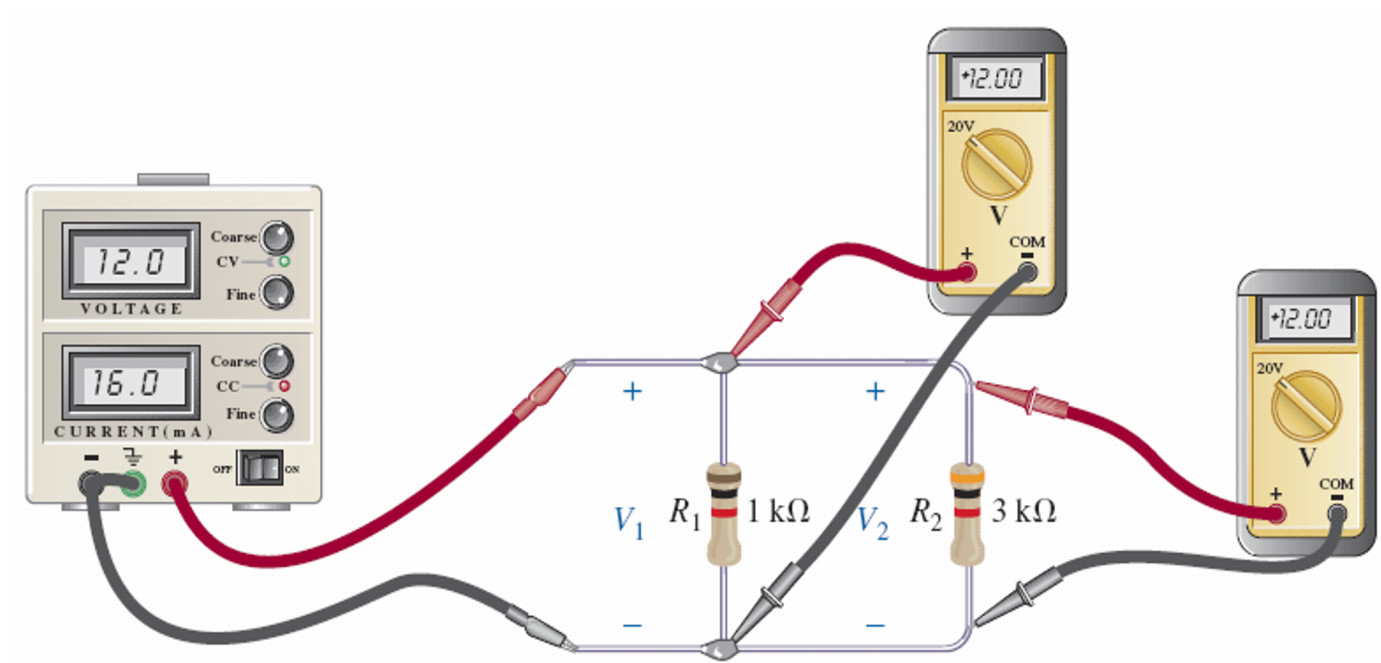


FIG. 6.25 *Measuring the voltages of a parallel dc network.*

PARALLEL CIRCUITS

Instrumentation

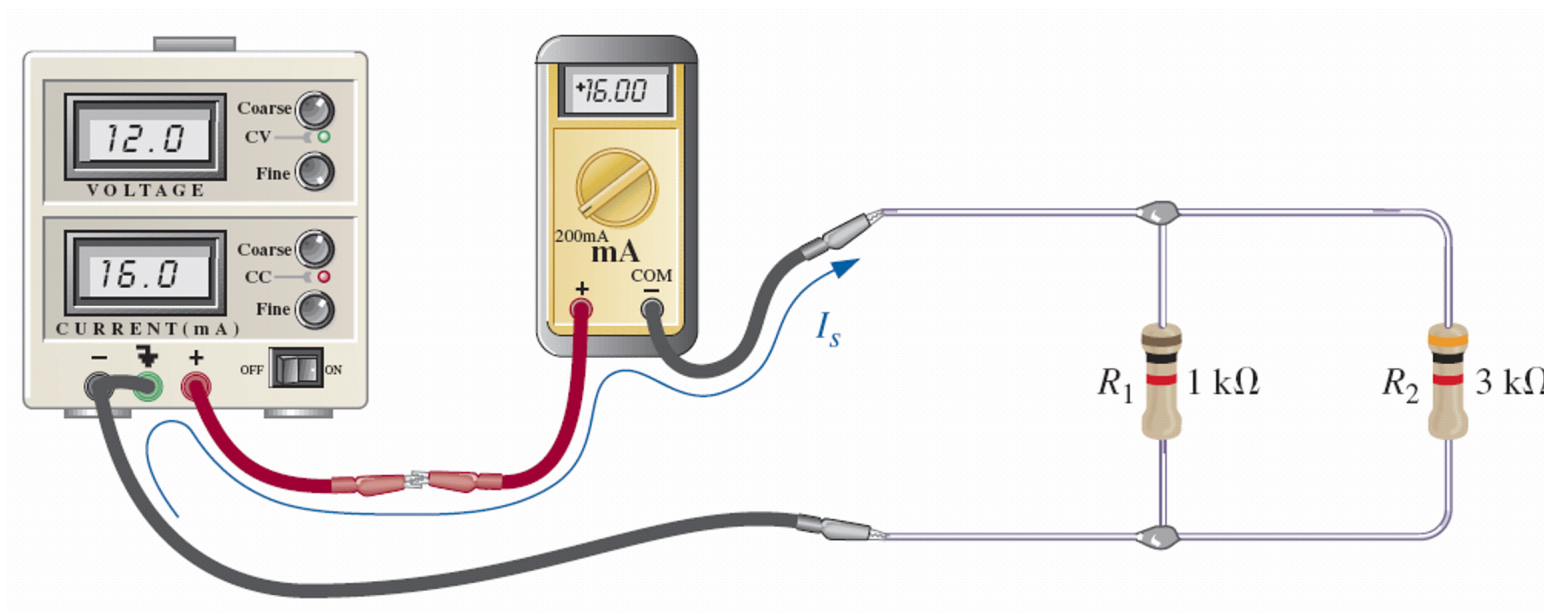


FIG. 6.26 *Measuring the source current of a parallel network.*

PARALLEL CIRCUITS

Instrumentation

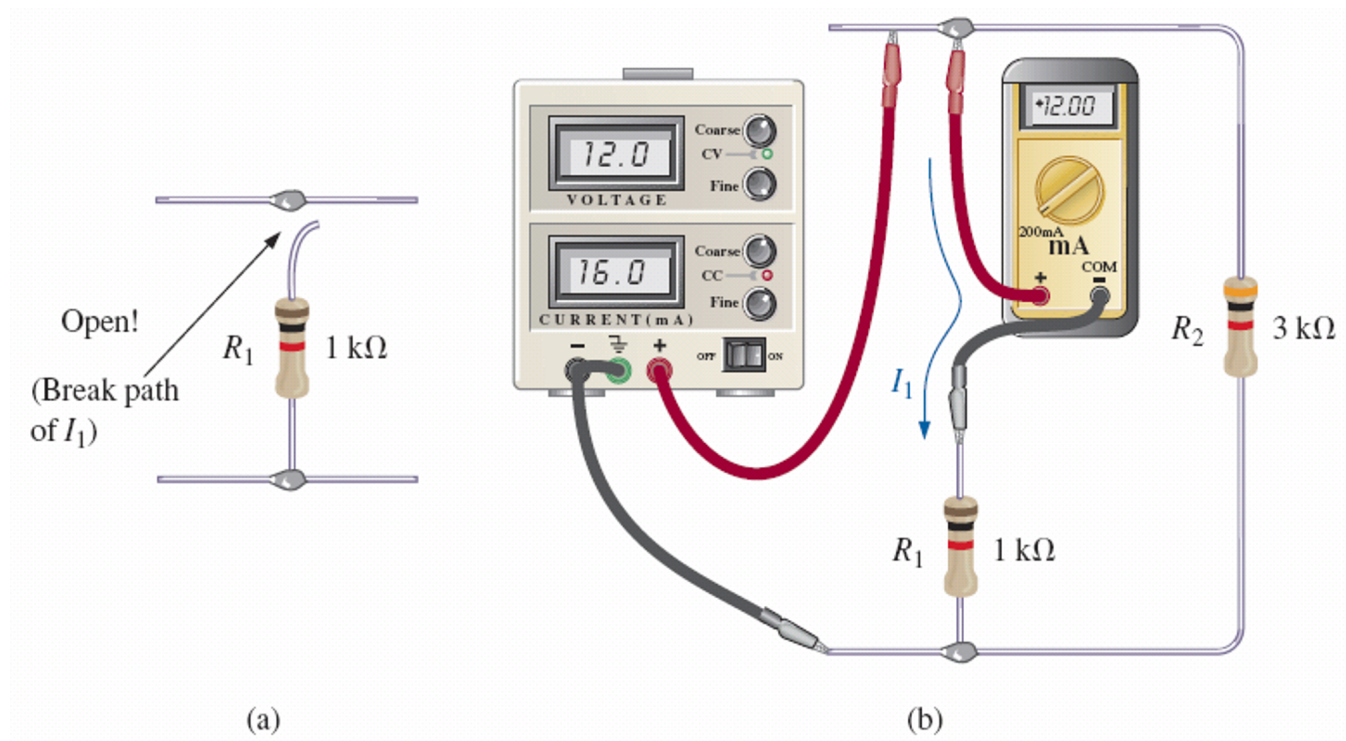


FIG. 6.27 *Measuring the current through resistor R_1 .*

POWER DISTRIBUTION IN A PARALLEL CIRCUIT

- Recall from the discussion of series circuits that the power applied to a series resistive circuit equals the power dissipated by the resistive elements.
- The same is true for parallel resistive networks.
 - In fact, for any network composed of resistive elements, the power applied by the battery will equal that dissipated by the resistive elements.

POWER DISTRIBUTION IN A PARALLEL CIRCUIT

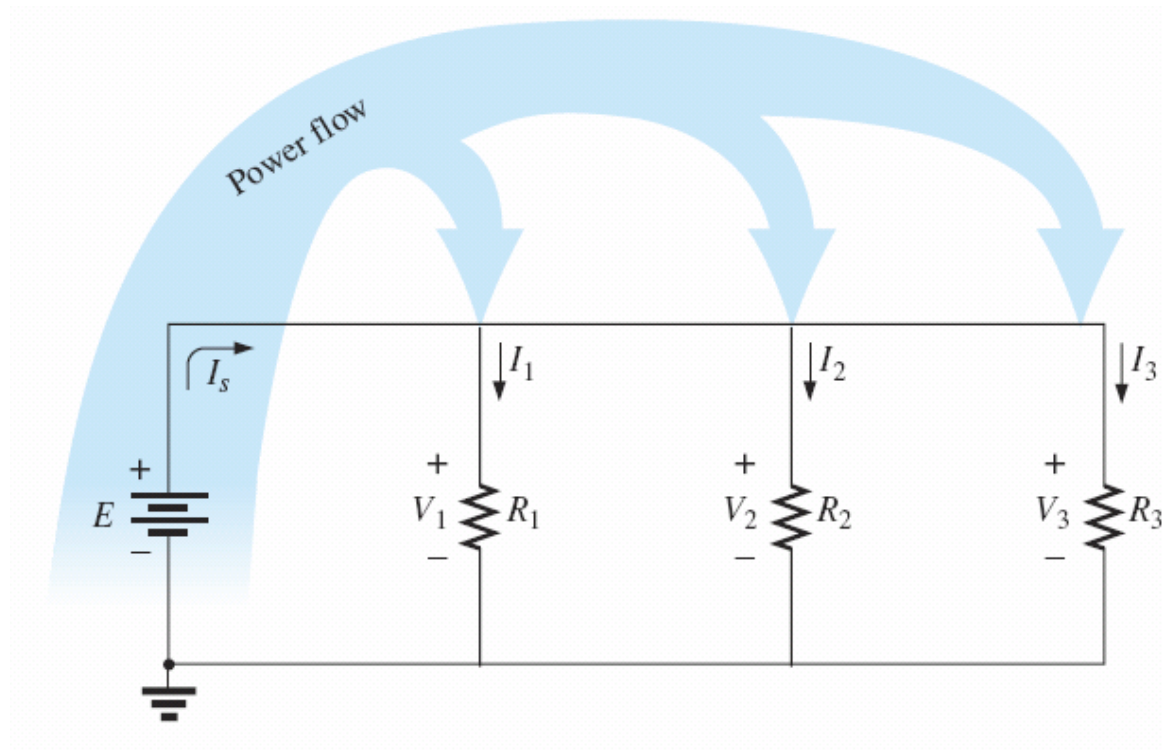


FIG. 6.28 *Power flow in a dc parallel network.*

POWER DISTRIBUTION IN A PARALLEL CIRCUIT

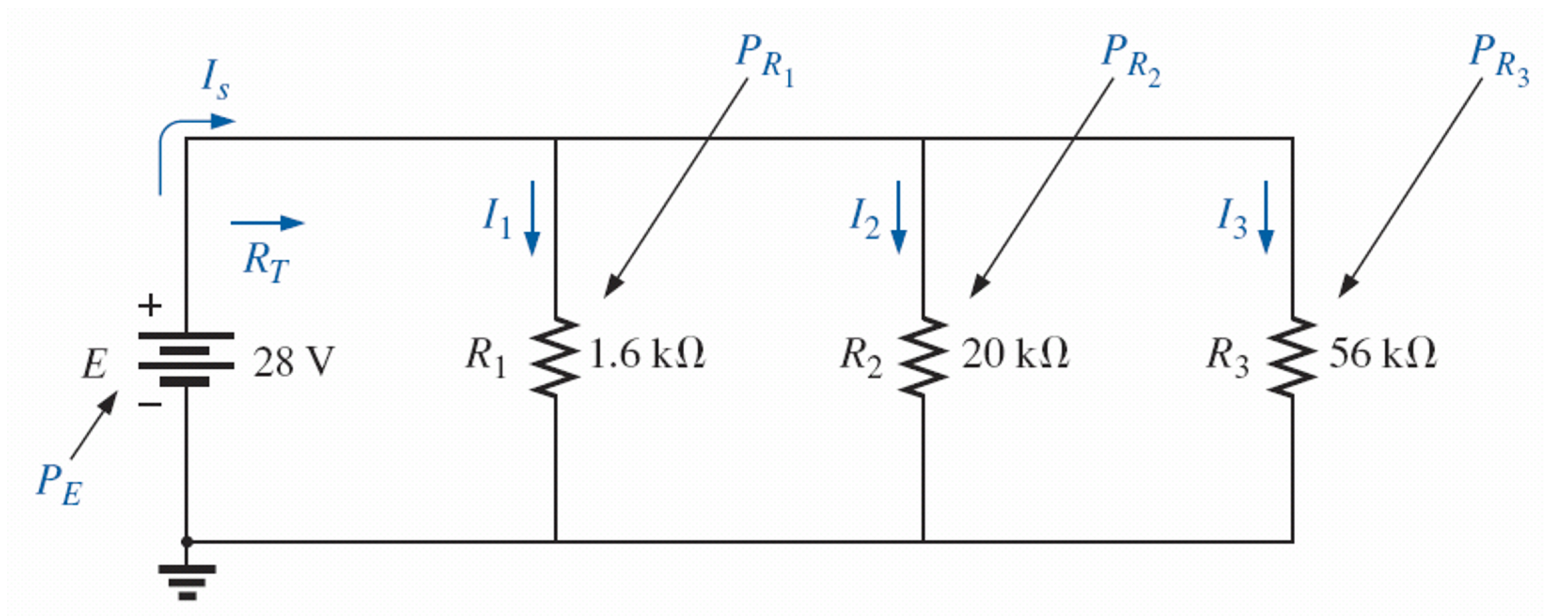


FIG. 6.29 *Parallel network for Example 6.15.*

KIRCHHOFF'S CURRENT LAW

- In the previous chapter, Kirchhoff's voltage law was introduced, providing a very important relationship among the voltages of a closed path.

KIRCHHOFF'S CURRENT LAW

- Kirchhoff is also credited with developing the following equally important relationship between the currents of a network, called Kirchhoff's current law (KCL):
 - The algebraic sum of the currents entering and leaving a junction (or region) of a network is zero.

KIRCHHOFF'S CURRENT LAW

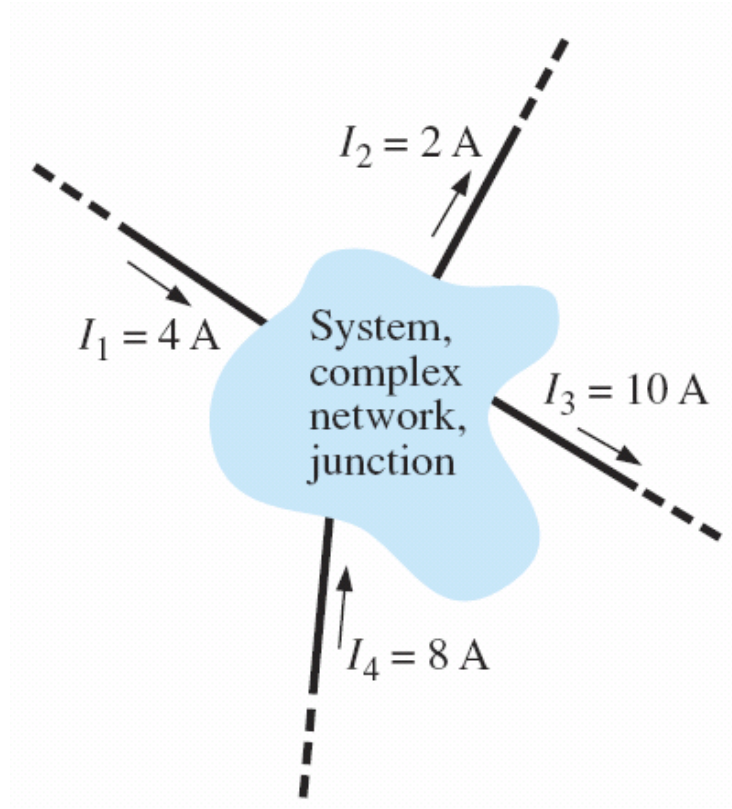


FIG. 6.30 *Introducing Kirchhoff's current law.*

KIRCHHOFF'S CURRENT LAW

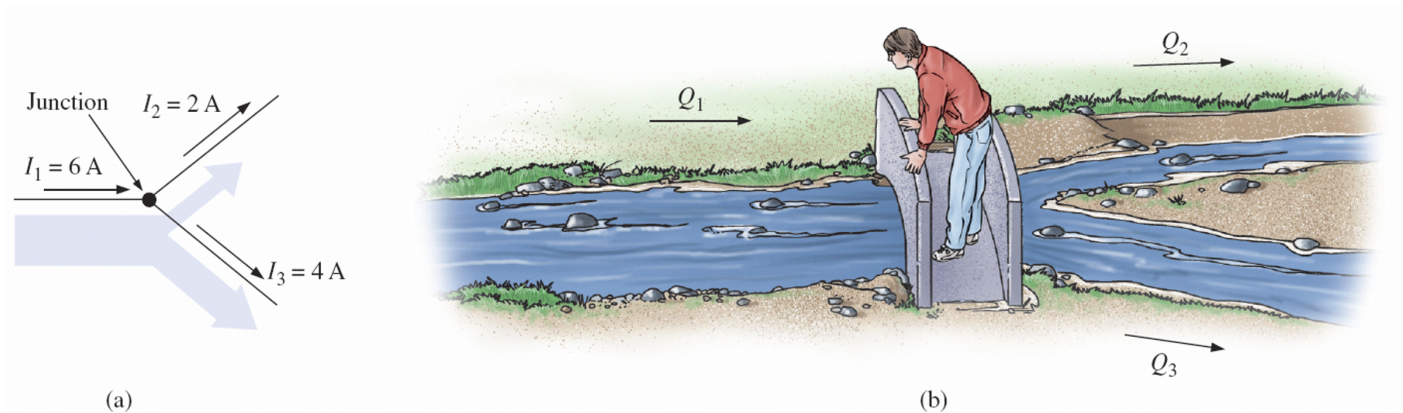


FIG. 6.31 (a) Demonstrating Kirchhoff's current law; (b) the water analogy for the junction in (a).

KIRCHHOFF'S CURRENT LAW

- In technology, the term node is commonly used to refer to a junction of two or more branches.

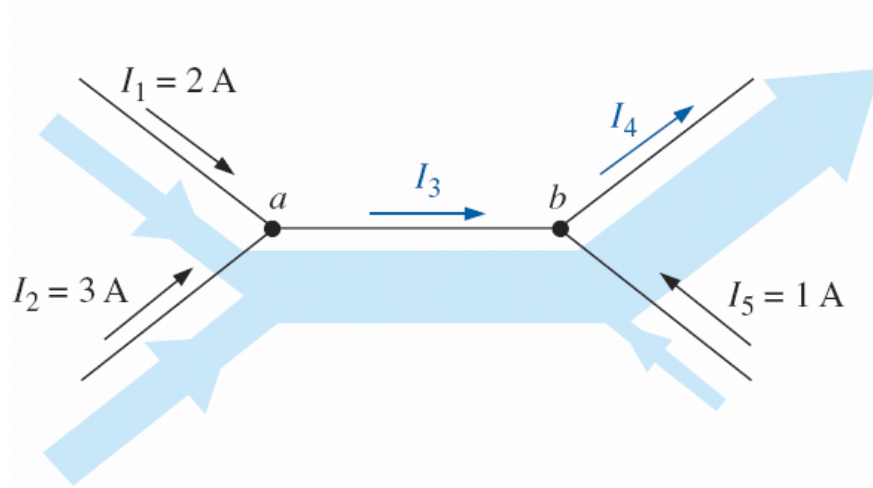


FIG. 6.32 *Two-node configuration for Example 6.16.*

KIRCHHOFF'S CURRENT LAW

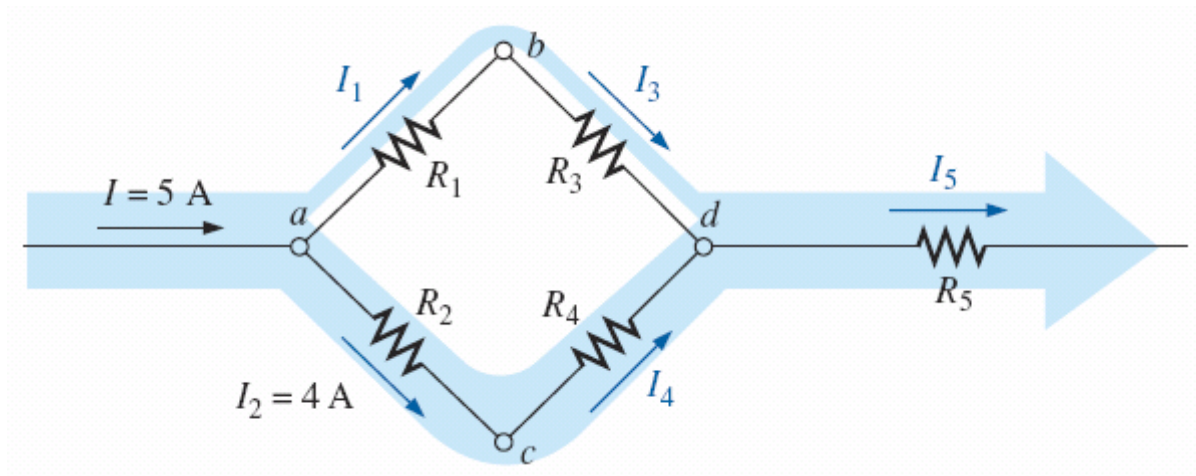


FIG. 6.33 *Four-node configuration for Example 6.17.*

KIRCHHOFF'S CURRENT LAW

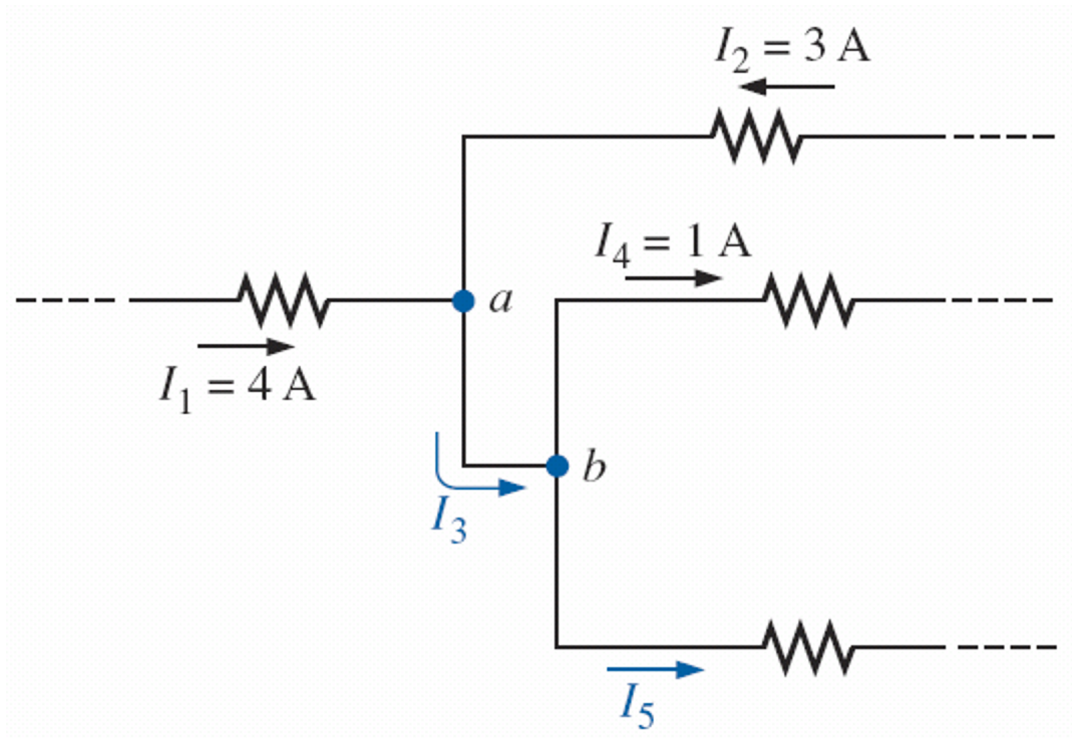


FIG. 6.34 Network for
Example 6.18.

KIRCHHOFF'S CURRENT LAW

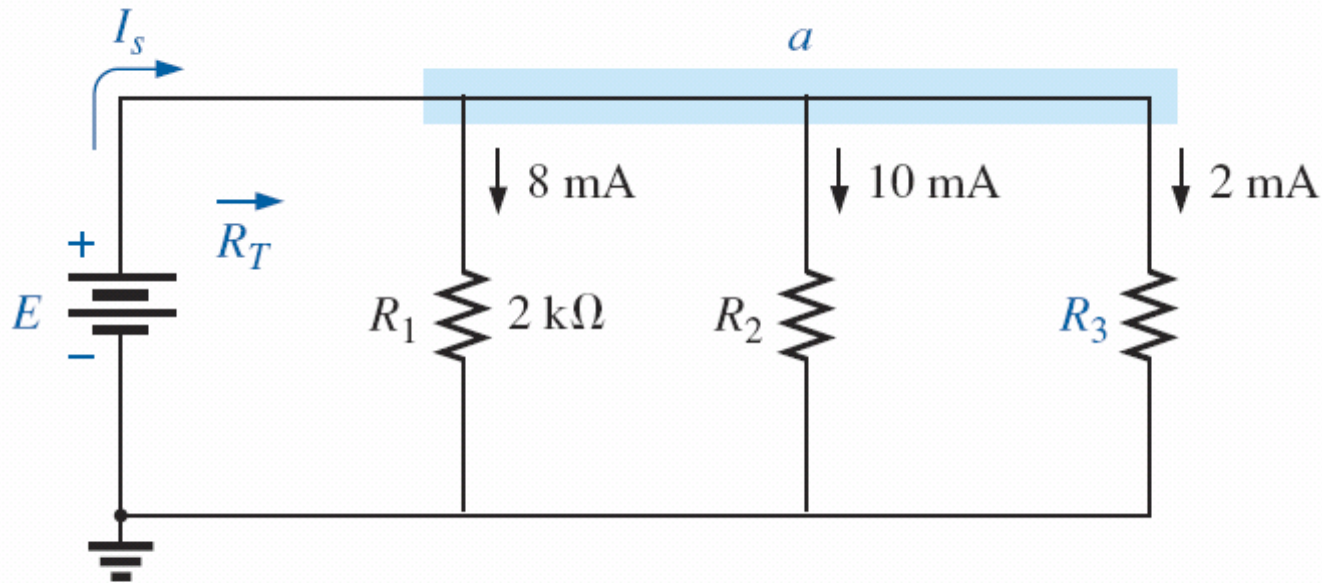


FIG. 6.35 *Parallel network for Example 6.19.*

KIRCHHOFF'S CURRENT LAW

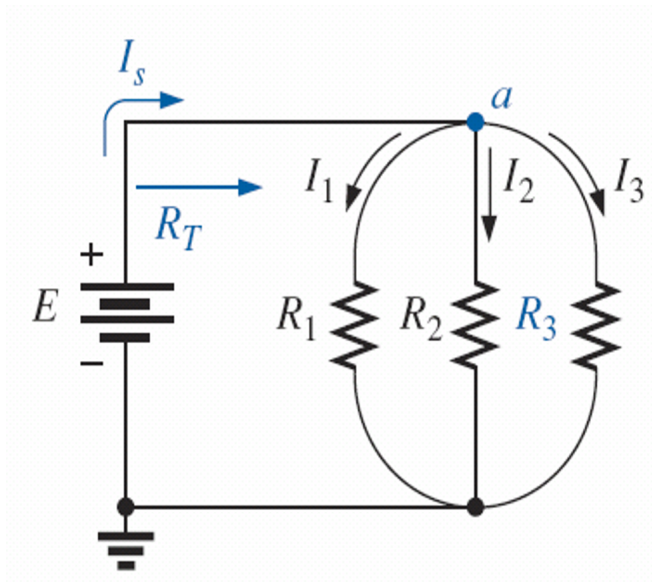


FIG. 6.36 Redrawn network in Fig. 6.35.

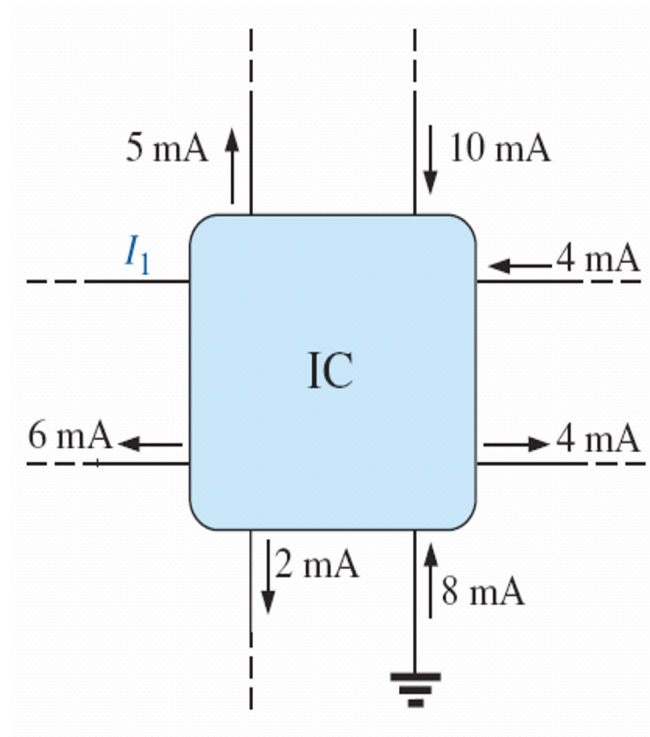


FIG. 6.37 Integrated circuit for Example 6.20.

CURRENT DIVIDER RULE

- For series circuits we have the powerful voltage divider rule for finding the voltage across a resistor in a series circuit.
- We now introduce the equally powerful current divider rule (CDR) for finding the current through a resistor in a parallel circuit.

CURRENT DIVIDER RULE

- In general:
 - For two parallel elements of equal value, the current will divide equally.
 - For parallel elements with different values, the smaller the resistance, the greater is the share of input current.
 - For parallel elements of different values, the current will split with a ratio equal to the inverse of their resistance values.

CURRENT DIVIDER RULE

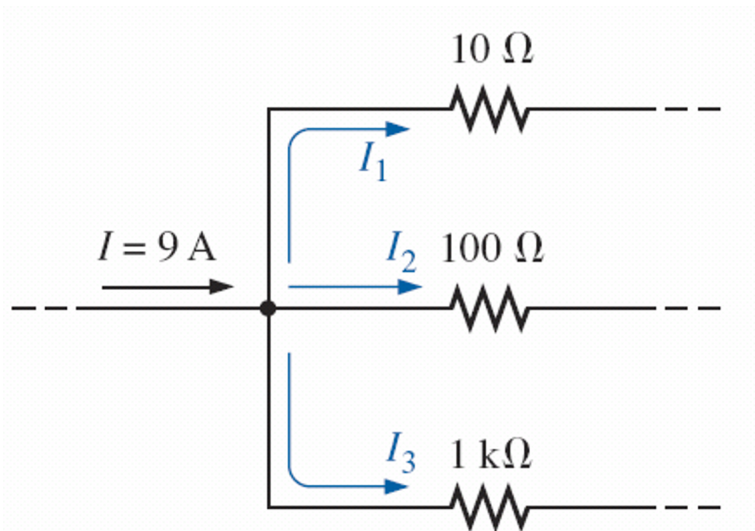


FIG. 6.38 *Discussing the manner in which the current will split between three parallel branches of different resistive value.*

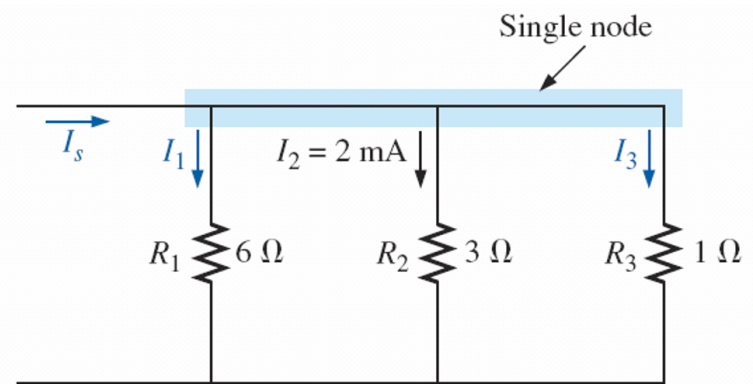


FIG. 6.39 *Parallel network for Example 6.21.*

CURRENT DIVIDER RULE

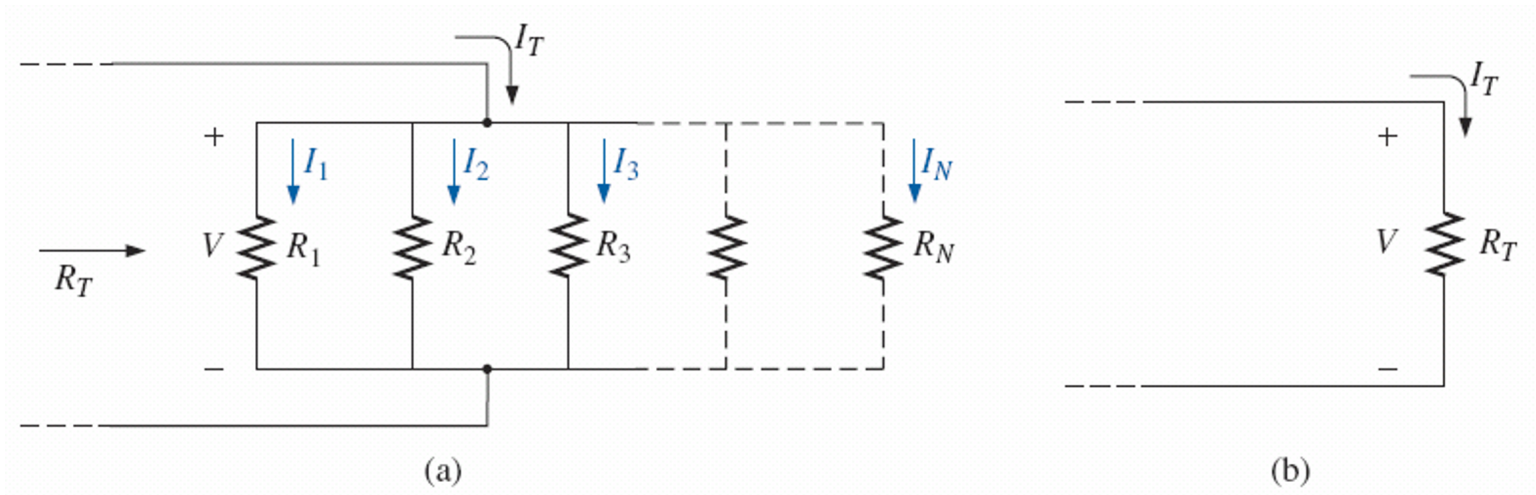


FIG. 6.40 Deriving the current divider rule: (a) parallel network of N parallel resistors; (b) reduced equivalent of part (a).

CURRENT DIVIDER RULE

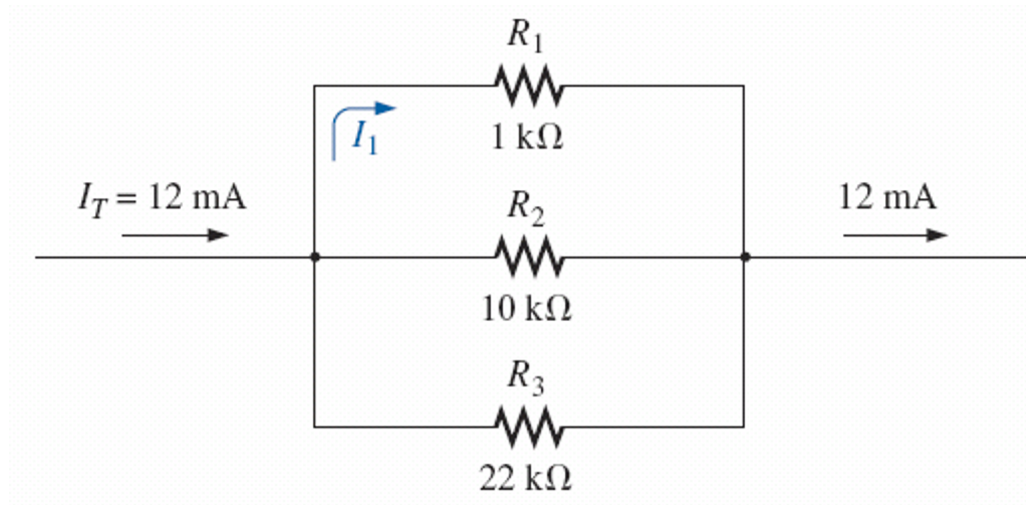


FIG. 6.41 *Using the current divider rule to calculate current I_1 in Example 6.22.*

CURRENT DIVIDER RULE

- Note also that for a parallel network, the current through the smallest resistor will be very close to the total entering current if the other parallel elements of the configuration are much larger in magnitude.

CURRENT DIVIDER RULE: Special Case- Two Parallel Resistors

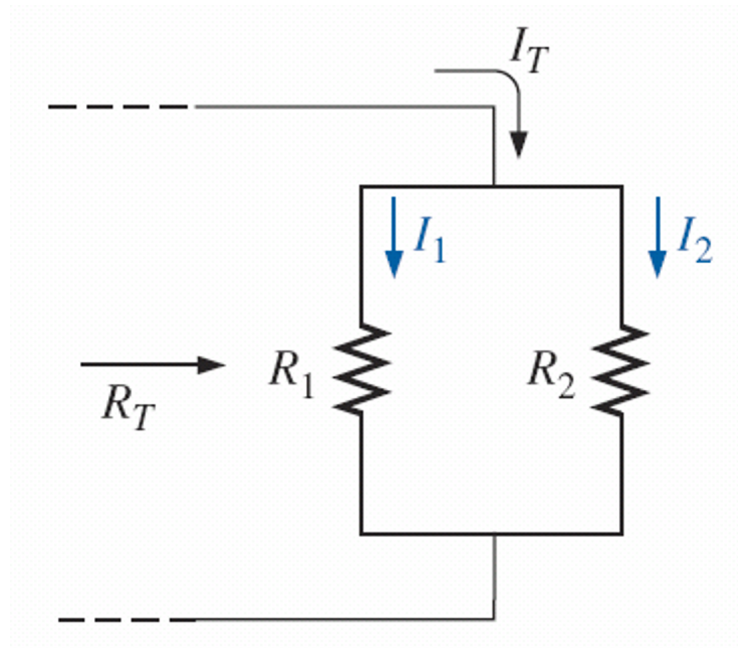


FIG. 6.42 *Deriving the current divider rule for the special case of only two parallel resistors.*

CURRENT DIVIDER RULE: Special Case- Two Parallel Resistors

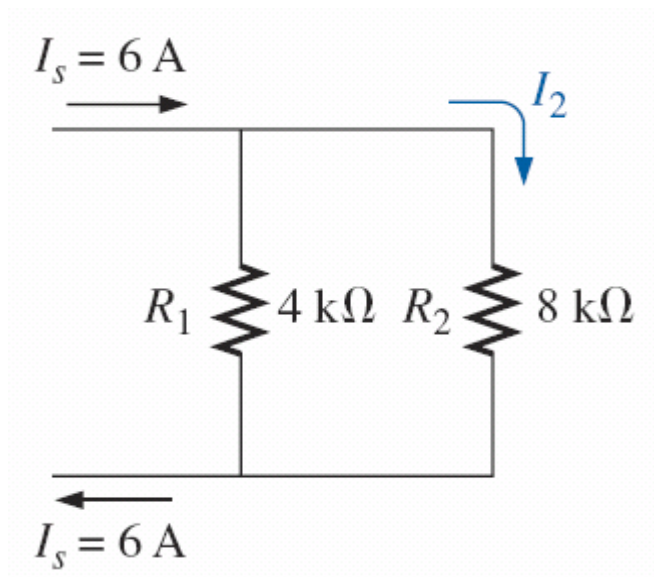


FIG. 6.43 Using the current divider rule to determine current I_2 in Example 6.23.

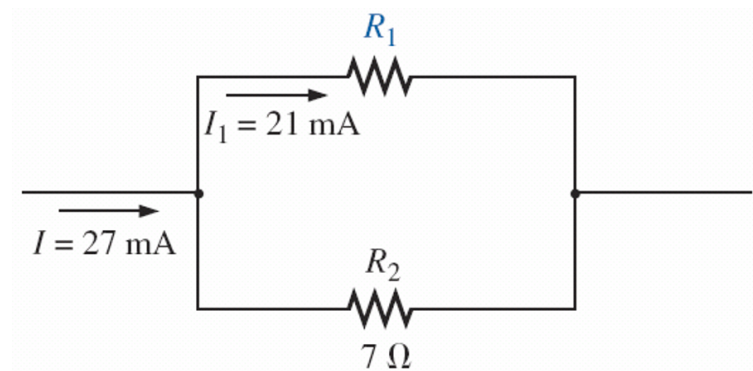


FIG. 6.44 A design-type problem for two parallel resistors (Example 6.24).

CURRENT DIVIDER RULE: Special Case- Two Parallel Resistors

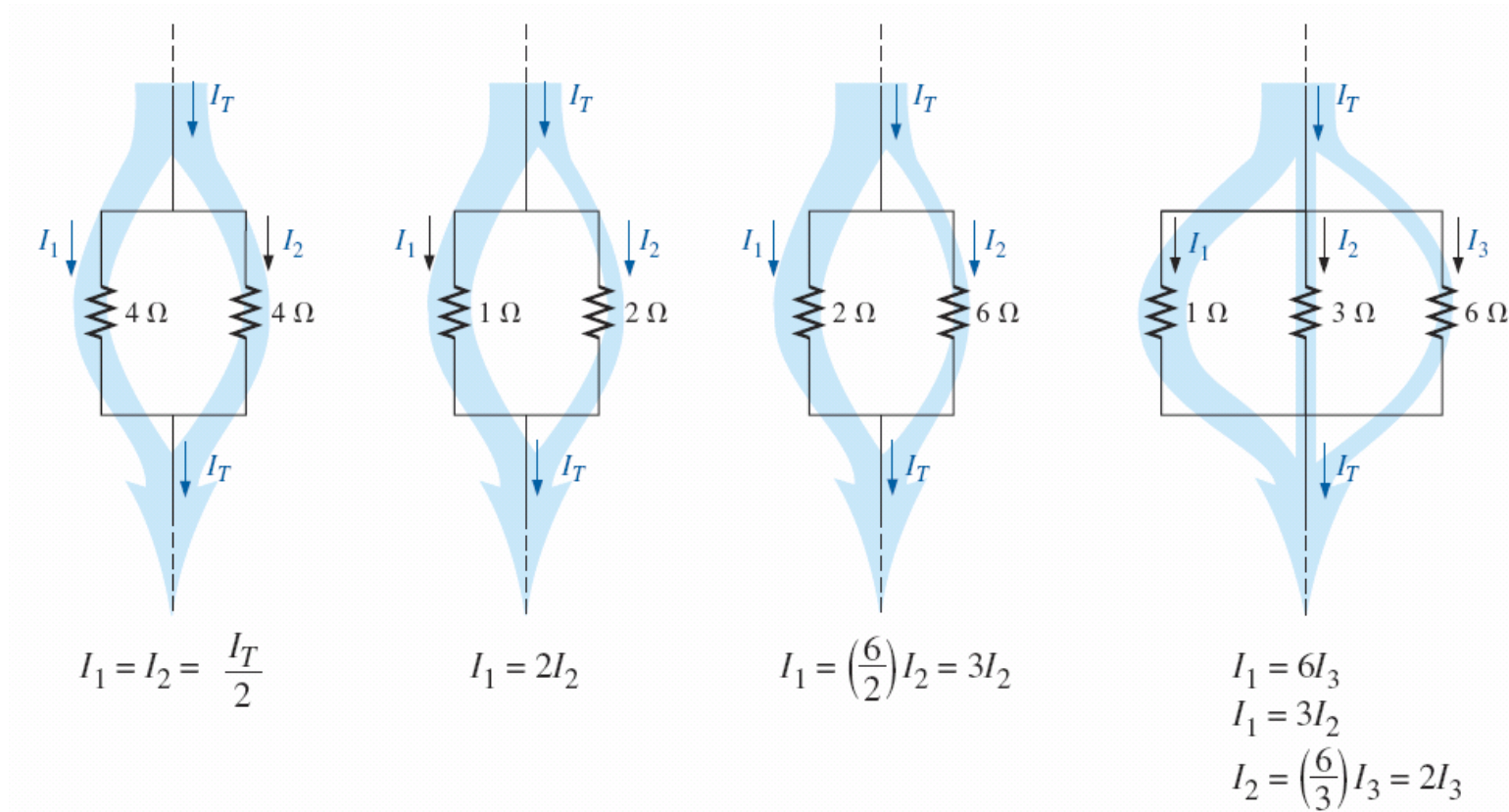


FIG. 6.45 *Demonstrating how current divides through equal and unequal parallel resistors.*

VOLTAGE SOURCES IN PARALLEL

- Because the voltage is the same across parallel elements, voltage sources can be placed in parallel only if they have the same voltage.
- The primary reason for placing two or more batteries or supplies in parallel is to increase the current rating above that of a single supply.

VOLTAGE SOURCES IN PARALLEL

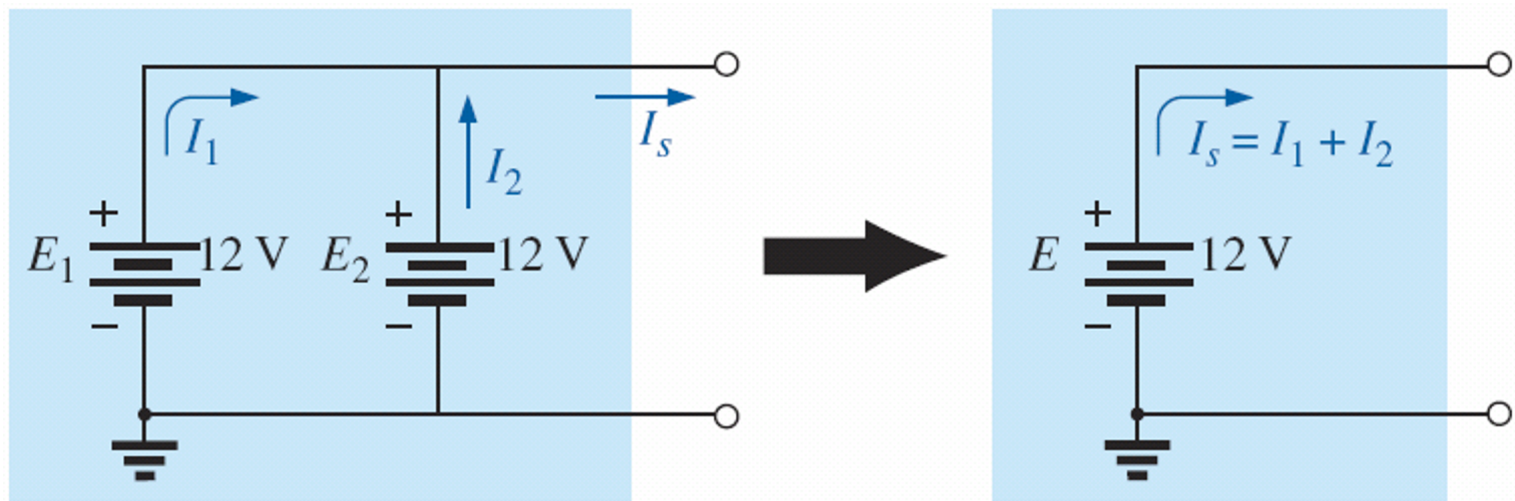


FIG. 6.46 *Demonstrating the effect of placing two ideal supplies of the same voltage in parallel.*

VOLTAGE SOURCES IN PARALLEL

- If for some reason two batteries of different voltages are placed in parallel, both will become ineffective or damaged because the battery with the larger voltage will rapidly discharge through the battery with the smaller terminal voltage.

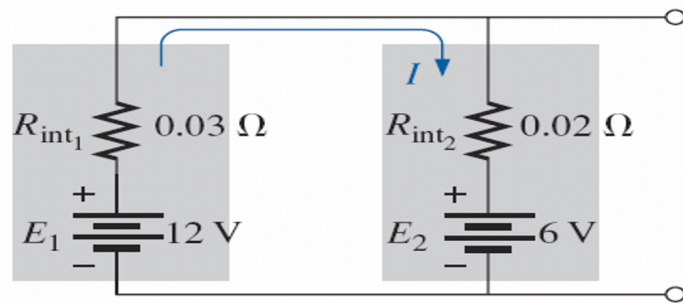


FIG. 6.47 *Examining the impact of placing two lead-acid batteries of different terminal voltages in parallel.*

VOLTAGE SOURCES IN PARALLEL

- In general, it is always recommended that when you are replacing batteries in series or parallel, replace all the batteries.

OPEN AND SHORT CIRCUITS

- Open circuits and short circuits can often cause more confusion and difficulty in the analysis of a system than standard series or parallel configurations.
- An open circuit is two isolated terminals not connected by an element of any kind.

OPEN AND SHORT CIRCUITS

- Since a path for conduction does not exist, the current associated with an open circuit must always be zero.
- The voltage across the open circuit, however, can be any value, as determined by the system it is connected to.

OPEN AND SHORT CIRCUITS

- In summary, therefore, an open circuit can have a potential difference (voltage) across its terminals, but the current is always zero amperes.

OPEN AND SHORT CIRCUITS

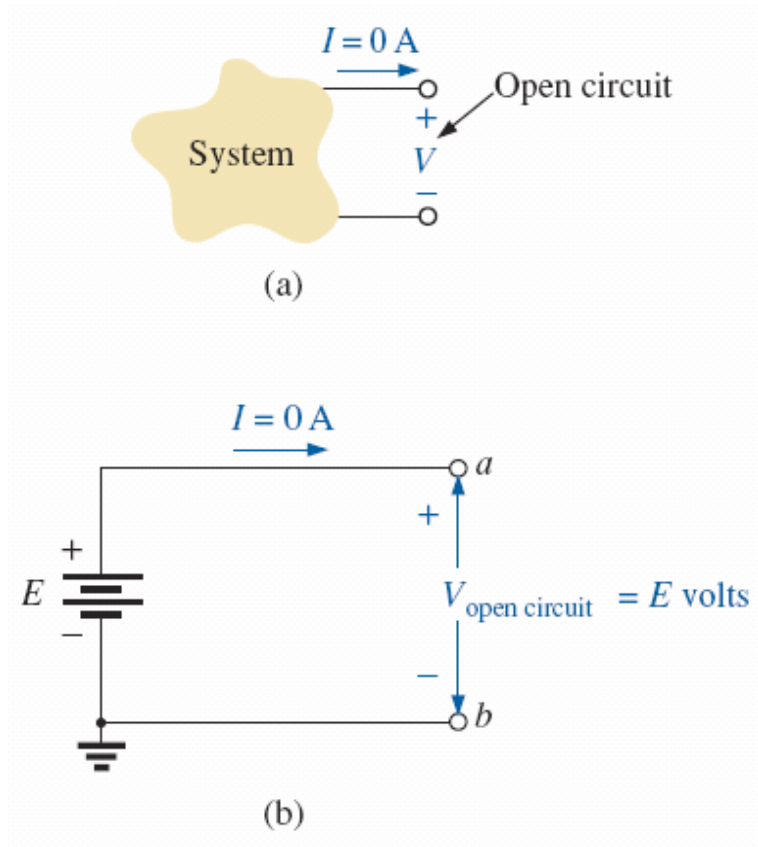


FIG. 6.48
Defining an open circuit.

OPEN AND SHORT CIRCUITS

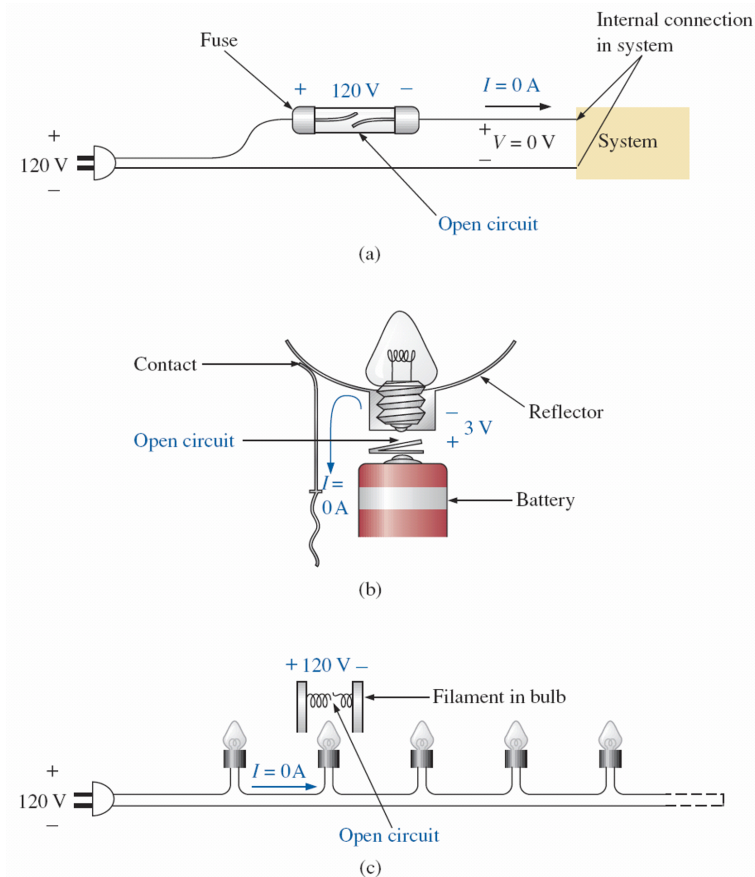


FIG. 6.49
Examples of open circuits.

OPEN AND SHORT CIRCUITS

- A short circuit is a very low resistance, direct connection between two terminals of a network.

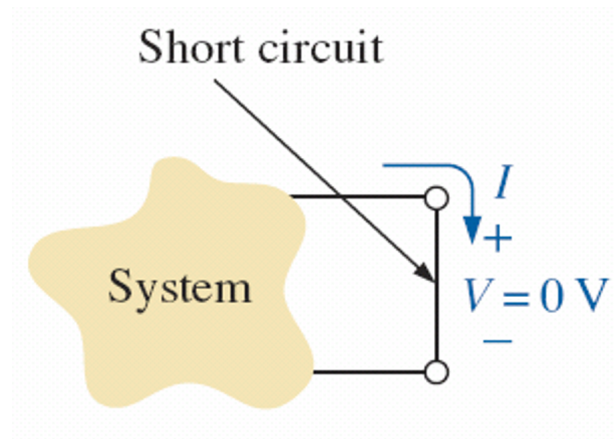


FIG. 6.50 *Defining a short circuit.*

OPEN AND SHORT CIRCUITS

- In summary, therefore, a short circuit can carry a current of a level determined by the external circuit, but the potential difference (voltage) across its terminals is always zero volts.

OPEN AND SHORT CIRCUITS

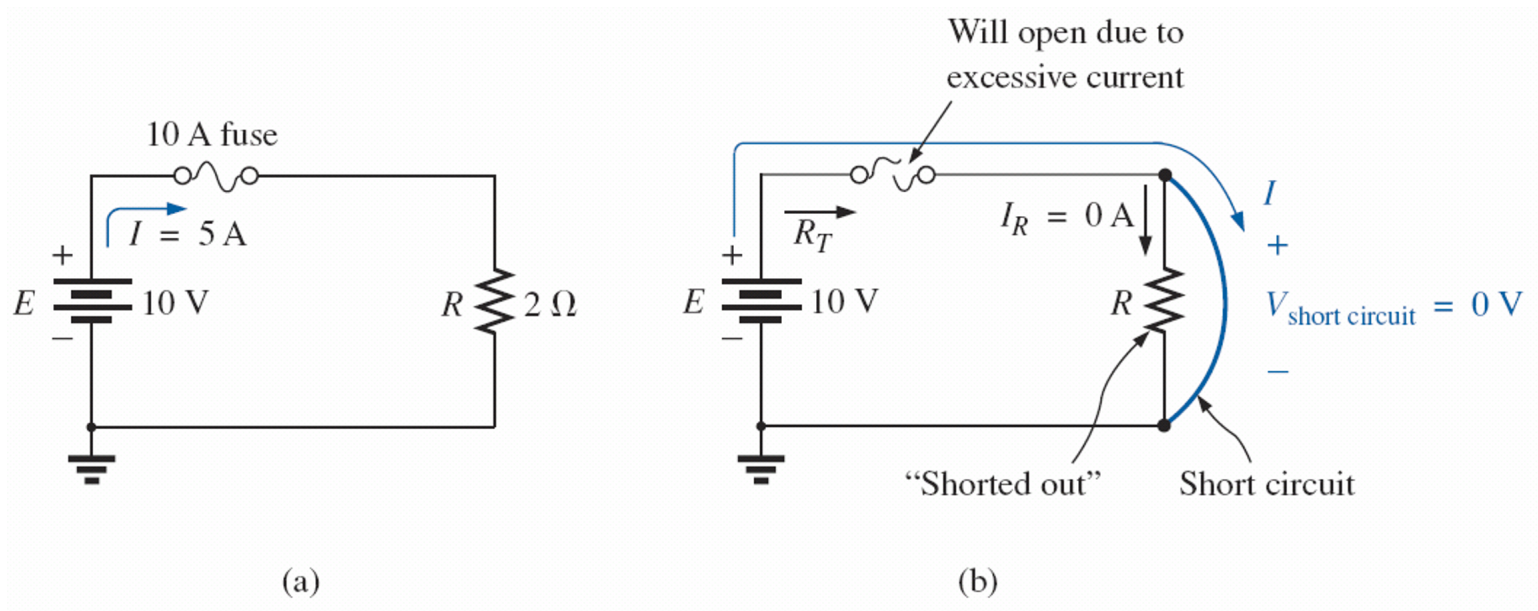


FIG. 6.51 *Demonstrating the effect of a short circuit on current levels.*

OPEN AND SHORT CIRCUITS

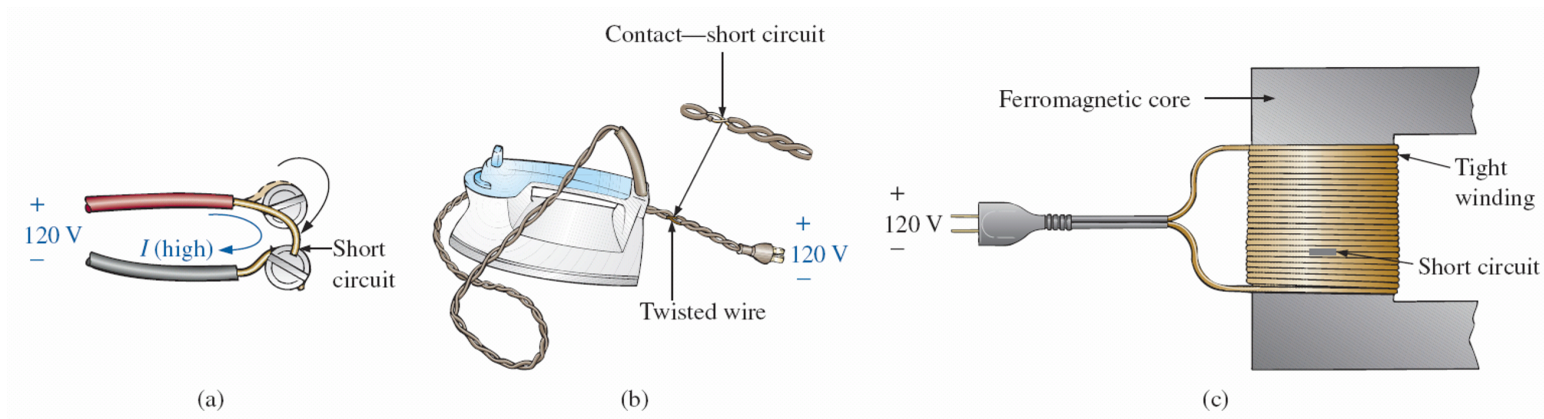


FIG. 6.52 *Examples of short circuits.*

VOLTMETER LOADING EFFECTS

- When you insert an ammeter, you actually introduce an additional resistance in series with the branch in which you are measuring the current.
- Generally, this is not a serious problem, but it can have a troubling effect on your readings, so it is important to be aware of it.

VOLTMETER LOADING EFFECTS

- Voltmeters also have an internal resistance that appears between the two terminals of interest when a measurement is being made.
- While an ammeter places an additional resistance in series with the branch of interest, a voltmeter places an additional resistance across the element.

VOLTMETER LOADING EFFECTS

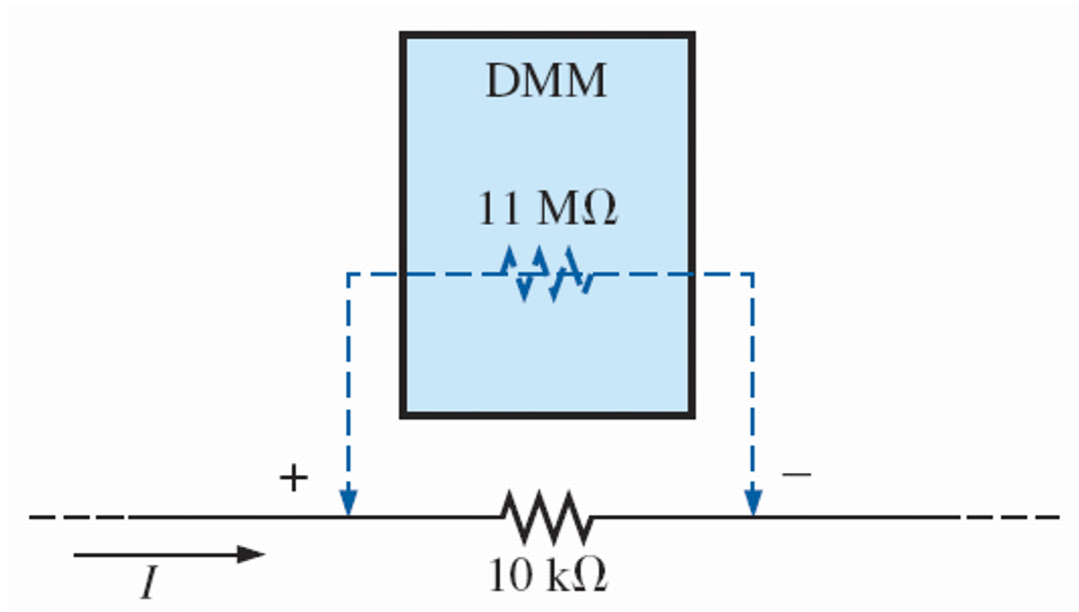


FIG. 6.53
*Voltmeter
loading.*

VOLTMETER LOADING EFFECTS

- Since it appears in parallel with the element of interest, the ideal level for the internal resistance of a voltmeter would be infinite ohms, just as zero ohms would be ideal for an ammeter.
- Unfortunately, the internal resistance of any voltmeter is not infinite and changes from one type of meter to another.

VOLTMETER LOADING EFFECTS

- Most digital voltmeters can be used in circuits with resistances up to the high-kilohm range without concern for the effect of the internal resistance on the reading.
- To determine the resistance R_m of any scale of a VOM:
 - Multiply the max voltage of the chosen scale by the ohm/volt rating appearing at the bottom of the face of the meter.

VOLTMETER LOADING EFFECTS

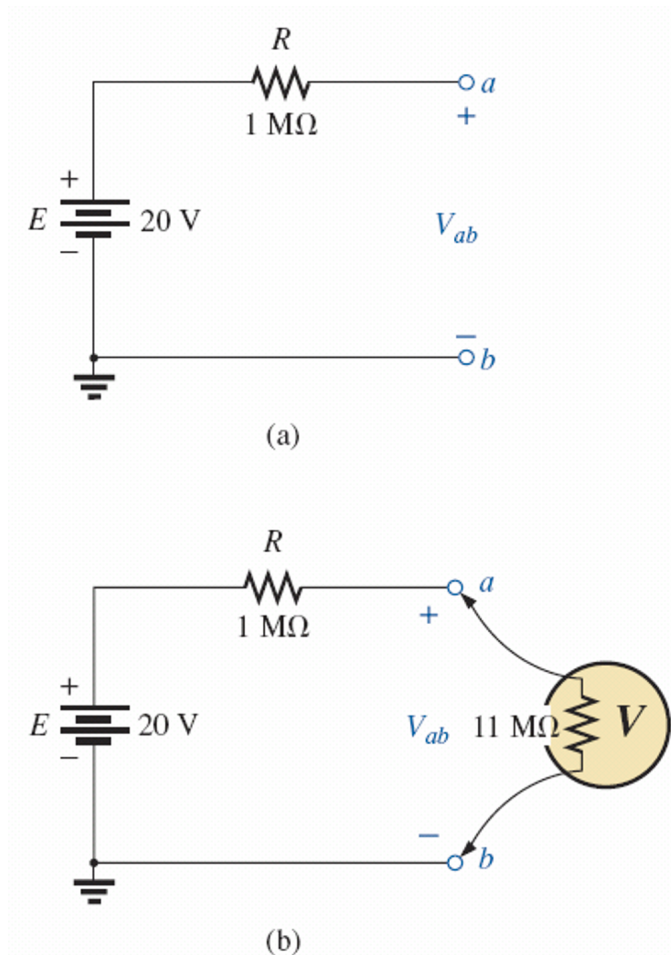


FIG. 6.54 (a) Measuring an open-circuit voltage with a voltmeter; (b) determining the effect of using a digital voltmeter with an internal resistance of $11\text{ M}\Omega$ on measuring an open-circuit voltage (Example 6.29).

SUMMARY TABLE

- Now that the series and parallel configurations have been covered in detail, we will review the salient equations and characteristics of each.
- The equations for one can often be obtained directly from the other by simply applying the duality principle.

SUMMARY TABLE

- Duality between equations means that the format for an equation can be applied to two different situations by just changing the variable of interest.

SUMMARY TABLE

Series and Parallel Circuits		
Series	Duality	Parallel
$R_T = R_1 + R_2 + R_3 + \cdots + R_N$	$R \nRightarrow G$	$G_T = G_1 + G_2 + G_3 + \cdots + G_N$
R_T increases (G_T decreases) if additional resistors are added in series	$R \nRightarrow G$	G_T increases (R_T decreases) if additional resistors are added in parallel
Special case: two elements $R_T = R_1 + R_2$	$R \nRightarrow G$	$G_T = G_1 + G_2$
I the same through series elements	$I \nRightarrow V$	V the same across parallel elements
$E = V_1 + V_2 + V_3$	$E, V \nRightarrow I$	$I_T = I_1 + I_2 + I_3$
Largest V across largest R	$V \nRightarrow I$ and $R \nRightarrow G$	Greatest I through largest G (smallest R)
$V_x = \frac{R_x E}{R_T}$	$E, V \nRightarrow I$ and $R \nRightarrow G$	$I_x = \frac{G_x I_T}{G_T}$
$P = EI_T$	$E \nRightarrow I$ and $I \nRightarrow E$	$P = I_T E$
$P = I^2 R$	$I \nRightarrow V$ and $R \nRightarrow G$	$P = V^2 G$
$P = V^2 / R$	$V \nRightarrow I$ and $R \nRightarrow G$	$P = I^2 / G$

TABLE 6.1
Summary table.

TROUBLESHOOTING TECHNIQUES

- The art of troubleshooting is not limited solely to electrical or electronic systems.
 - In the broad sense, troubleshooting is a process by which acquired knowledge and experience are used to localize a problem and offer or implement a solution.

TROUBLESHOOTING TECHNIQUES

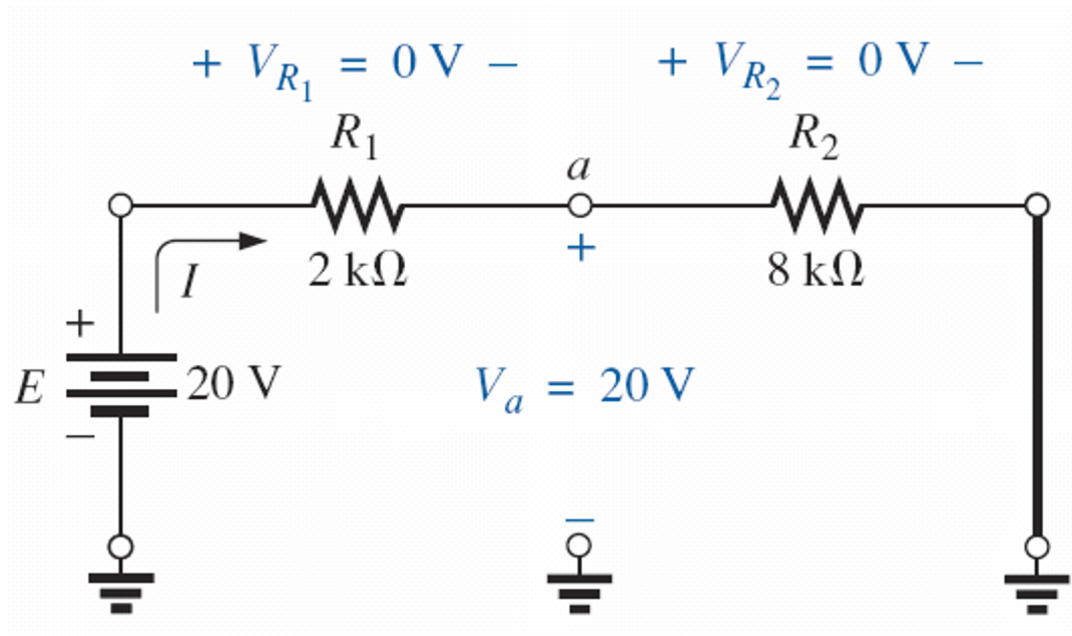


FIG. 6.55 A
*malfunctioning
network.*

PROTOBOARDS (BREADBOARDS)

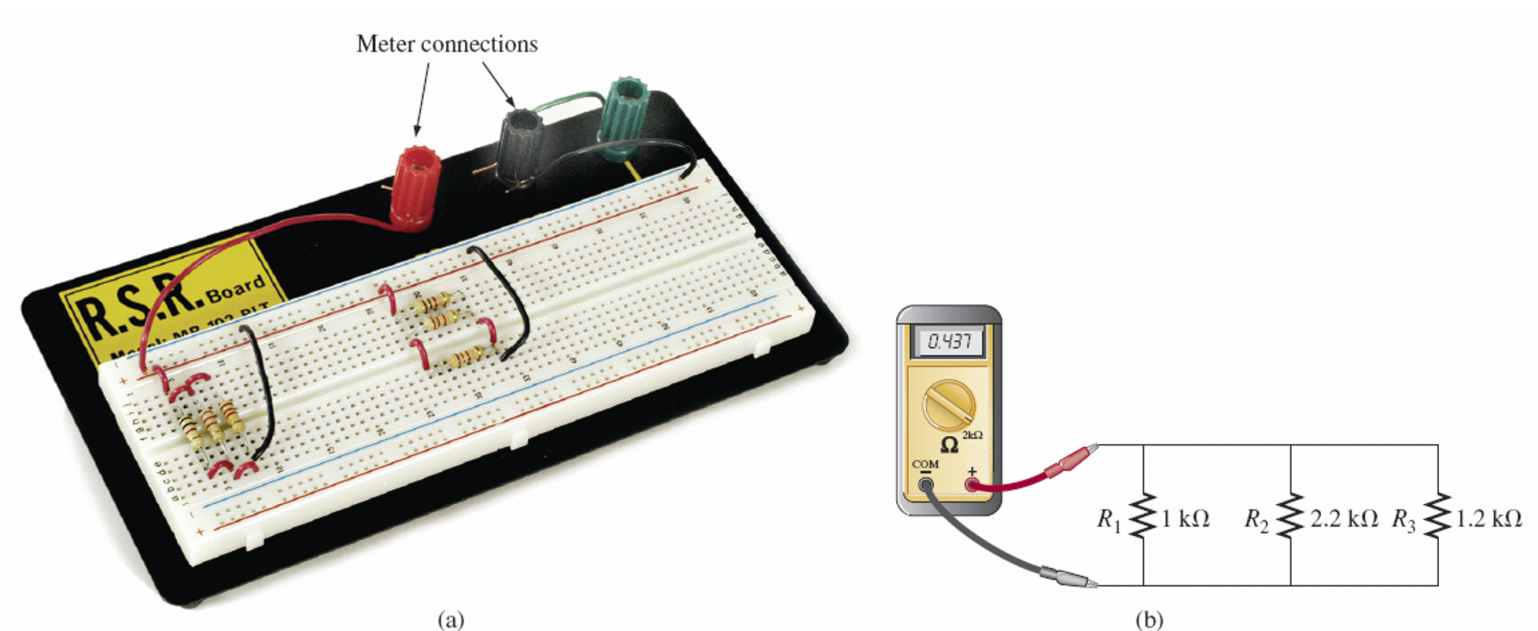


FIG. 6.56 *Using a protoboard to set up the circuit in Fig. 6.17.*

APPLICATIONS

- One of the most important advantages of the parallel configuration is that if one branch of the configuration should fail (open circuit), the remaining branches will still have full operating power.
- Another important advantage is that branches can be added at any time without affecting the behavior of those already in place.

APPLICATIONS

Car System

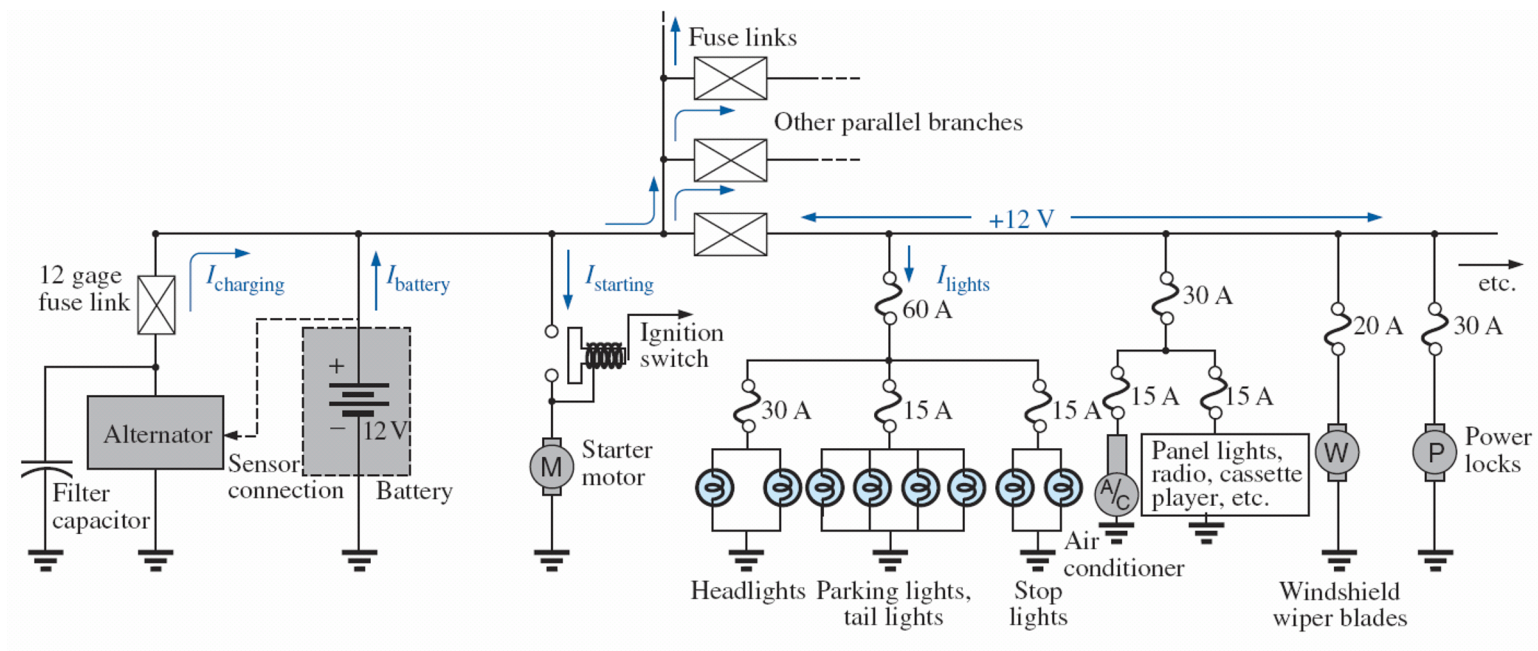


FIG. 6.57 *Expanded view of an automobile's electrical system.*

APPLICATIONS

Car System

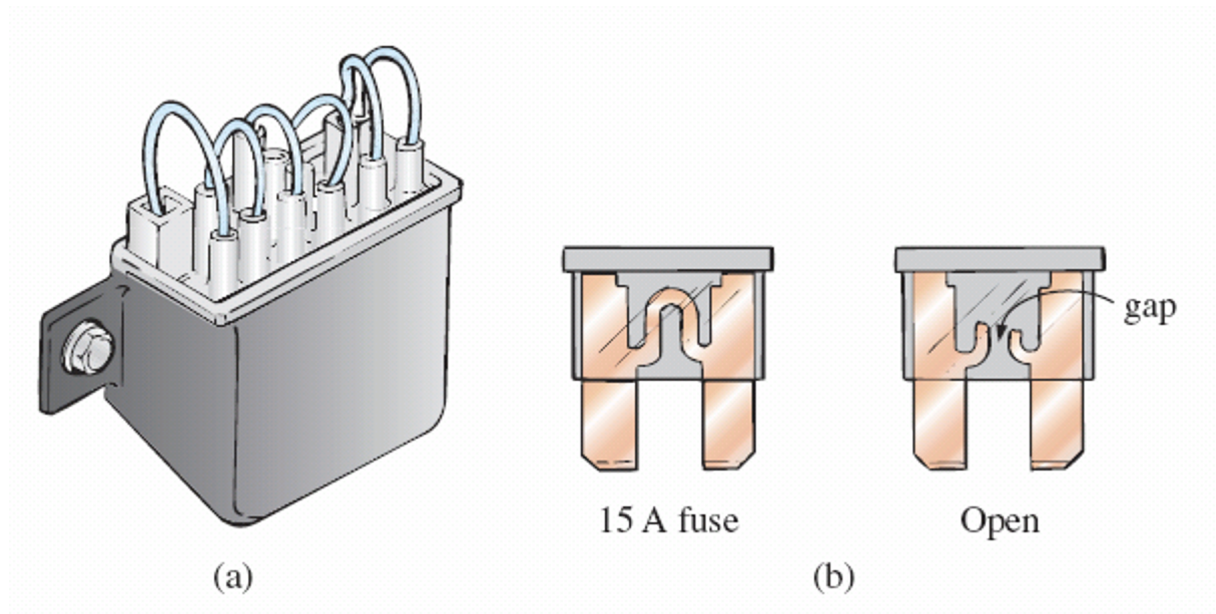


FIG. 6.58 *Car fuses: (a) fuse link; (b) plug-in.*

APPLICATIONS

House Wiring

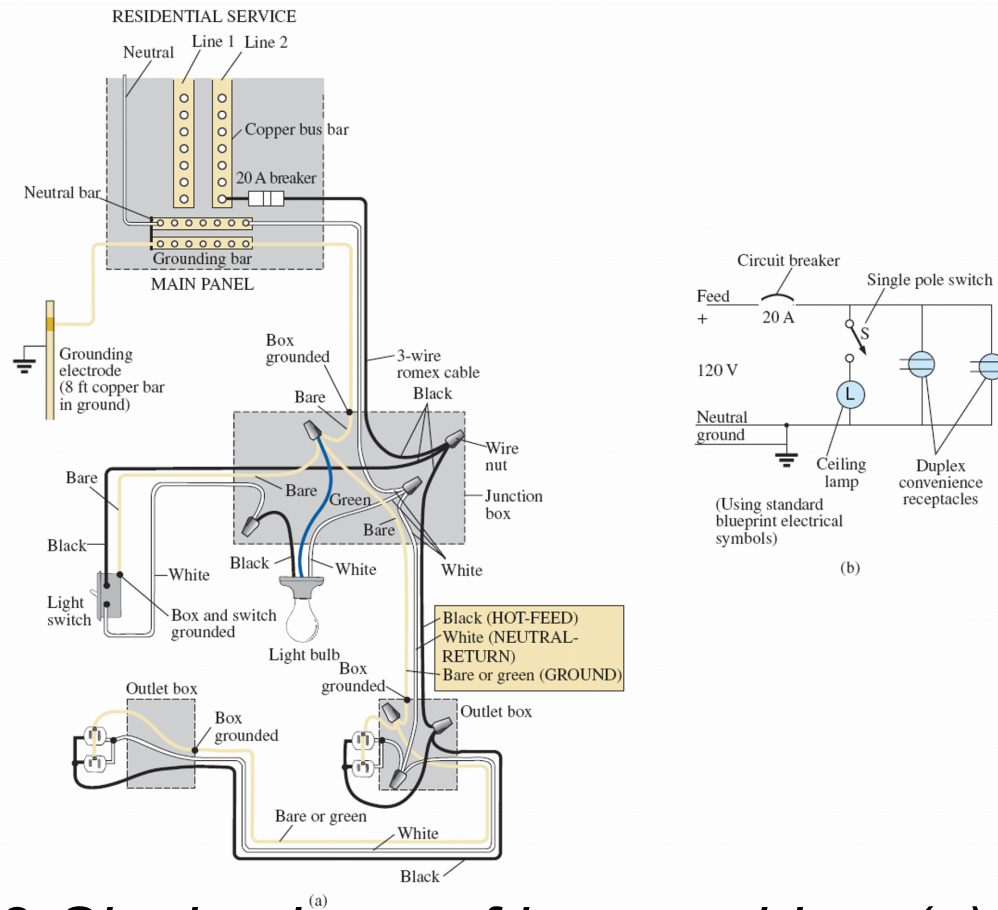


FIG. 6.59 Single phase of house wiring: (a) physical details; (b) schematic representation.

APPLICATIONS

House Wiring

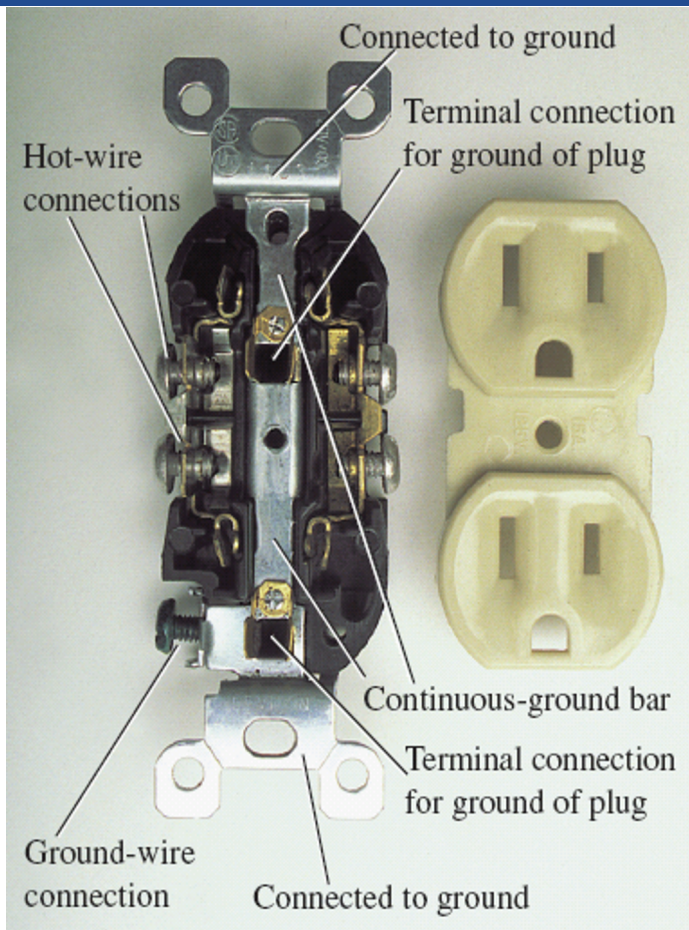


FIG. 6.60

Continuous ground connection in a duplex outlet.

APPLICATIONS

Parallel Computer Bus Connections

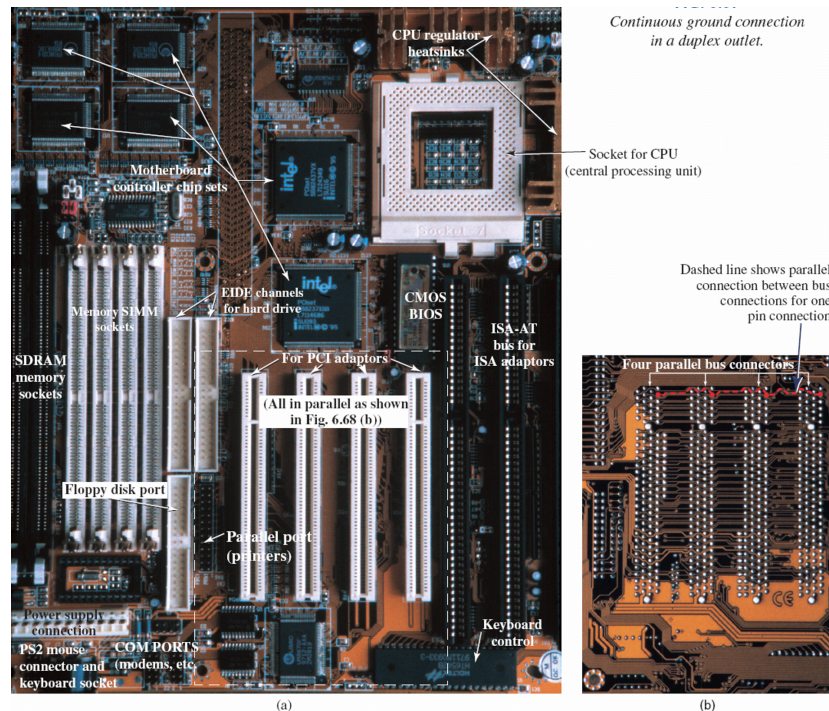


FIG. 6.61 (a) Motherboard for a desktop computer; (b) the printed circuit board connections for the region indicated in part (a).

COMPUTER ANALYSIS

PSpice

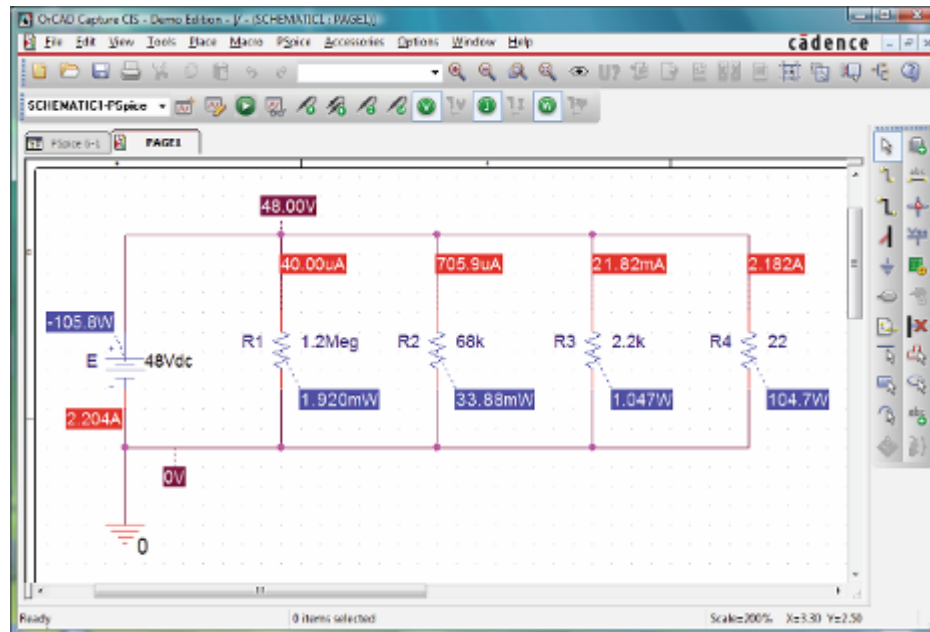


FIG. 6.62 *Applying PSpice to a parallel network.*

COMPUTER ANALYSIS

Multisim

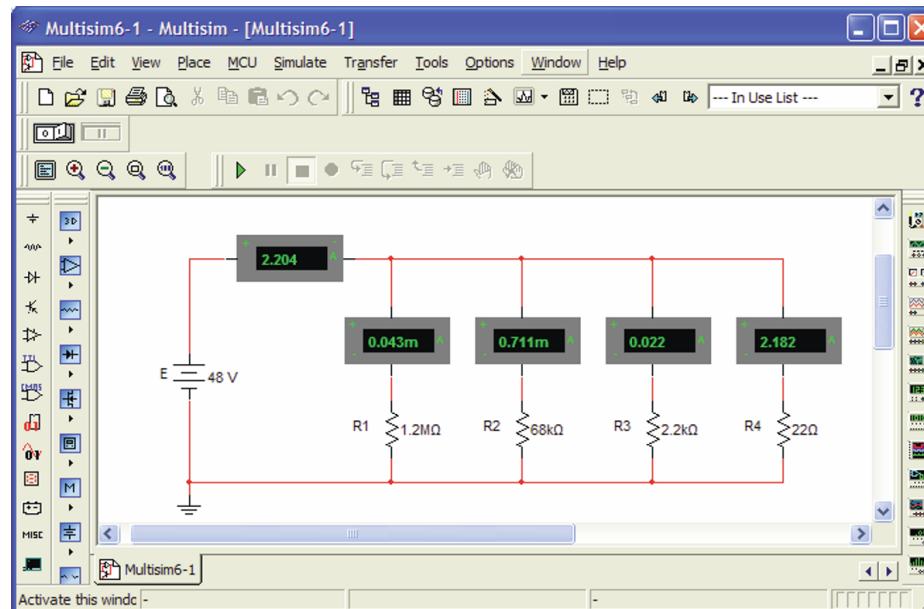
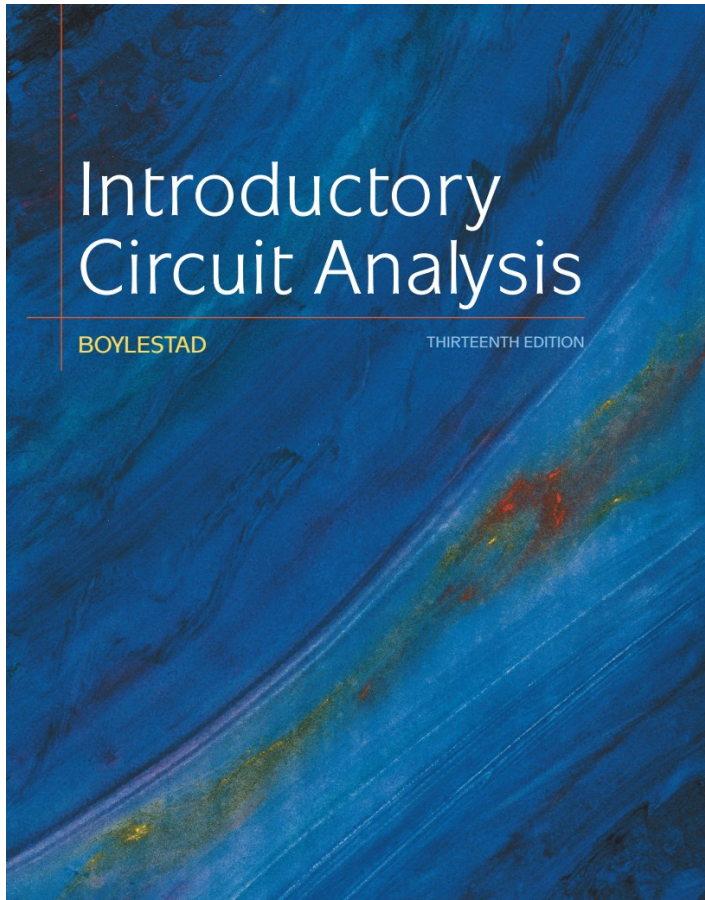


FIG. 6.63 *Using the indicators of Multisim to display the currents of a parallel dc network.*

Introductory Circuit Analysis



CHAPTER 7

Series-Parallel Circuits

OBJECTIVES

- Learn about the unique characteristics of series-parallel configurations and how to solve for the voltage, current, or power to any individual element or combination of elements.
- Become familiar with the voltage divider supply and the conditions needed to use it effectively.

OBJECTIVES

- Learn how to use a potentiometer to control the voltage across any given load.

INTRODUCTION

- A series-parallel configuration is one that is formed by a combination of series and parallel elements.
- A complex configuration is one in which none of the elements are in series or parallel.

SERIES-PARALLEL NETWORKS

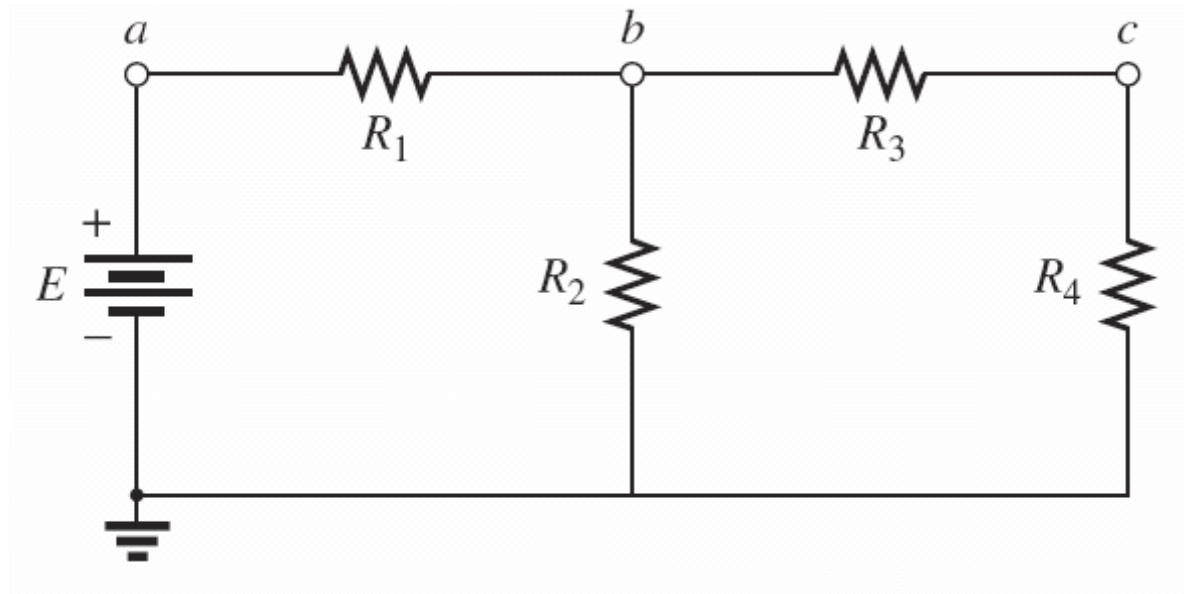


FIG. 7.1 *Series-parallel dc network.*

REDUCE AND RETURN APPROACH

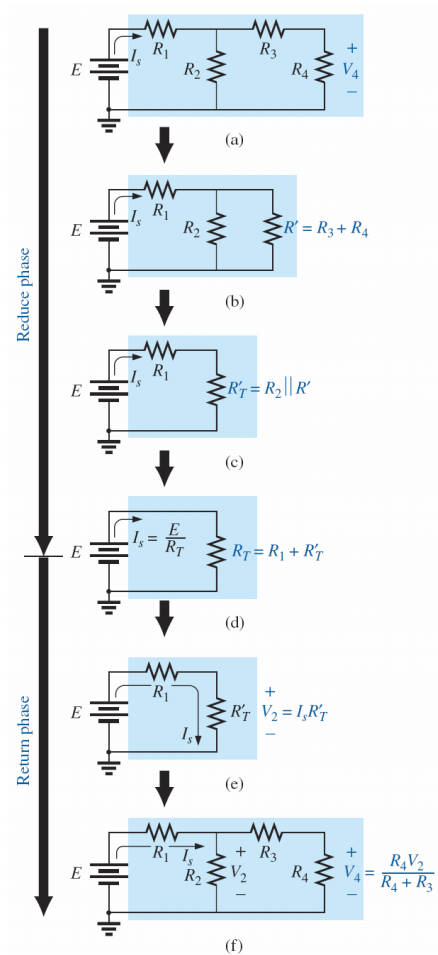


FIG. 7.2
*Introducing the
reduce and return
approach.*

REDUCE AND RETURN APPROACH

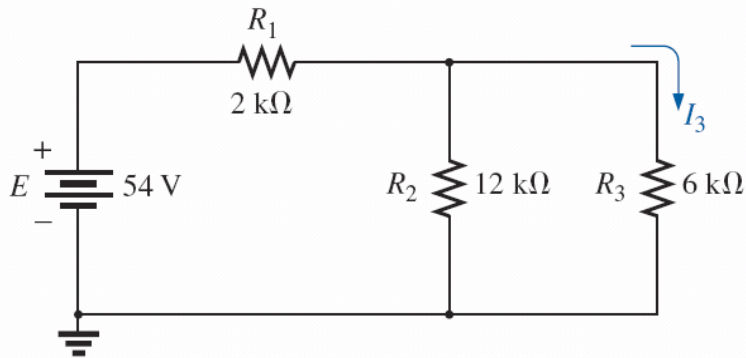


FIG. 7.3 Series-parallel network for Example 7.1.

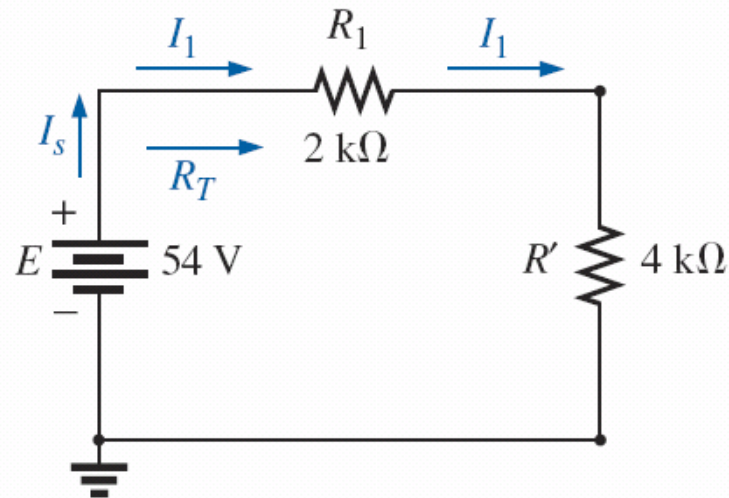


FIG. 7.4 Substituting the parallel equivalent resistance for resistors R_2 and R_3 in Fig. 7.3.

REDUCE AND RETURN APPROACH

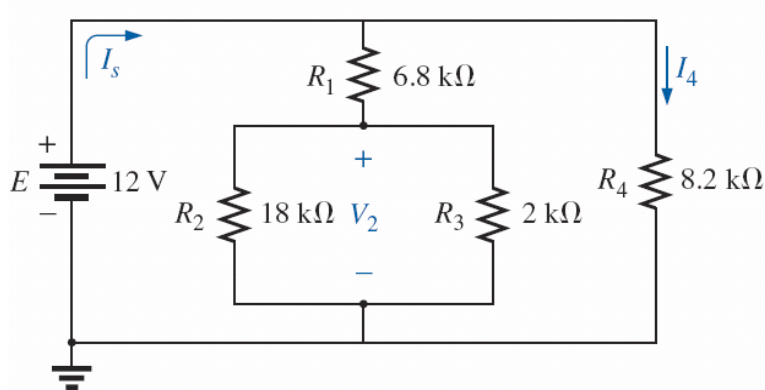


FIG. 7.5 Series-parallel network for Example 7.2.

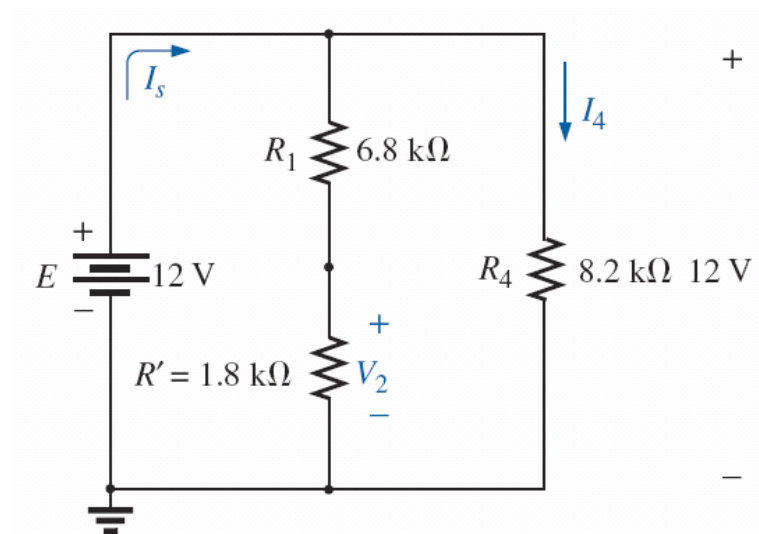


FIG. 7.6 Schematic representation of the network in Fig. 7.5 after substituting the equivalent resistance R for the parallel combination of R_2 and R_3 .

REDUCE AND RETURN APPROACH

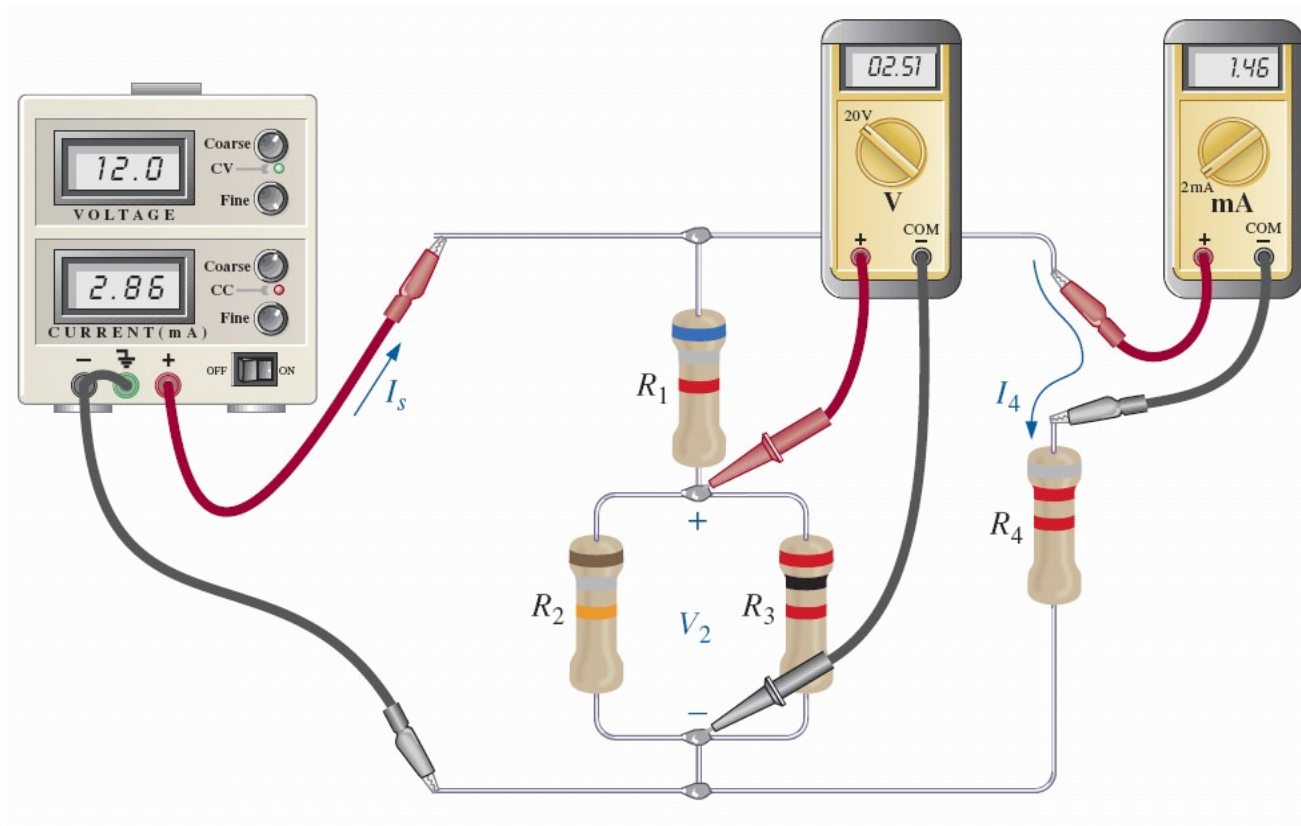


FIG. 7.7 Inserting an ammeter and a voltmeter to measure I_4 and V_2 , respectively.

BLOCK DIAGRAM APPROACH

- Once the grouping of elements reveals the most direct approach, you can examine the impact of the individual components in each group.
- This grouping of elements is called the block diagram approach

BLOCK DIAGRAM APPROACH

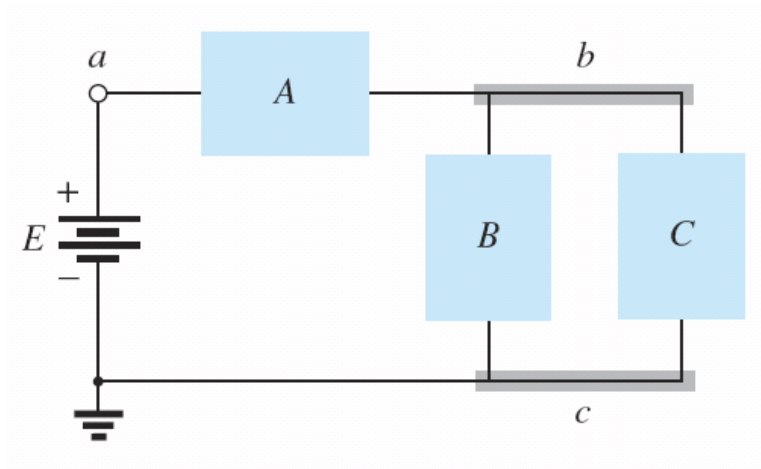


FIG. 7.8 *Introducing the block diagram approach.*

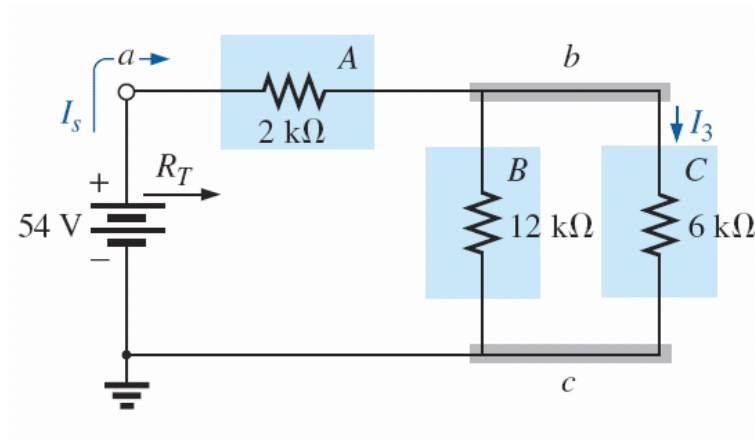


FIG. 7.9 *Block diagram format of Fig. 7.3.*

BLOCK DIAGRAM APPROACH

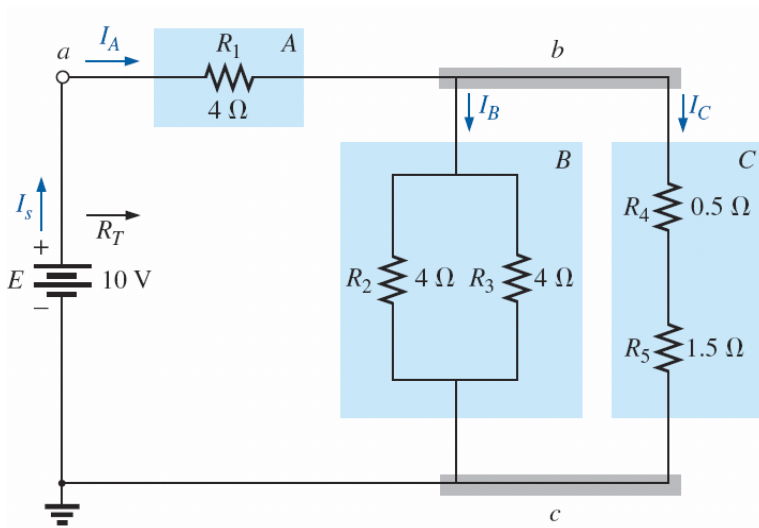


FIG. 7.10
Example 7.3.

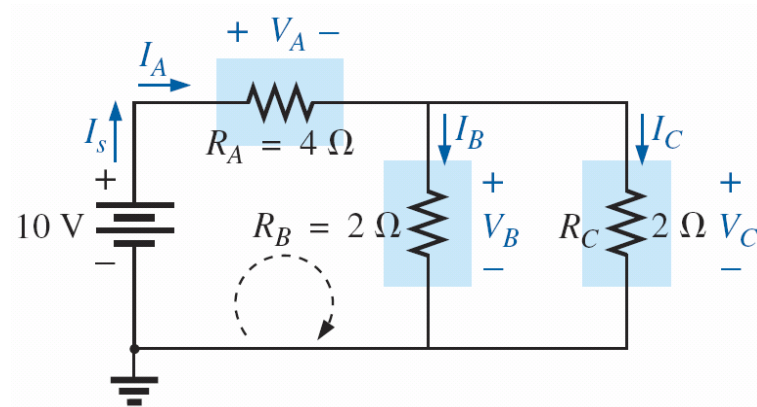


FIG. 7.11 *Reduced equivalent of Fig. 7.10.*

BLOCK DIAGRAM APPROACH

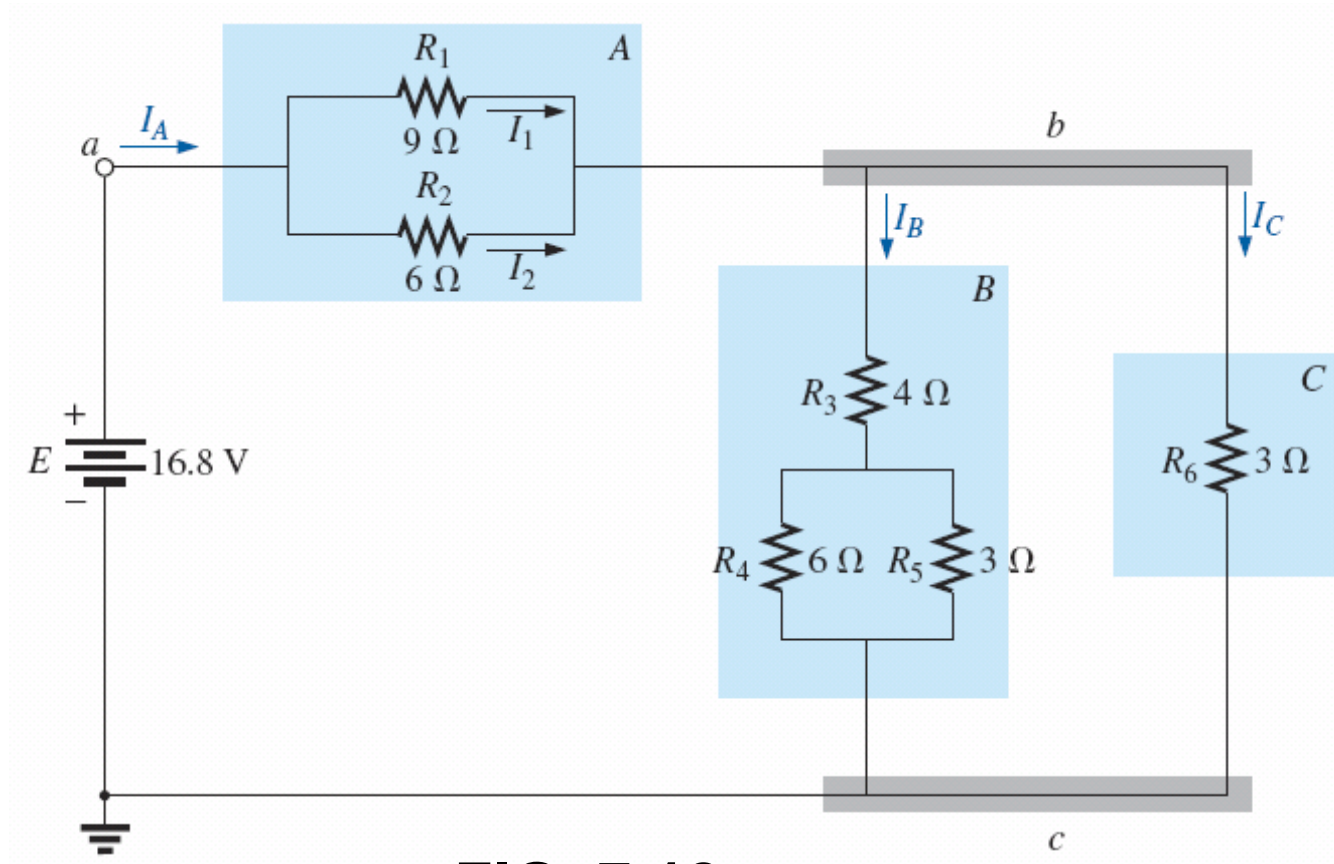


FIG. 7.12
Example 7.4.

BLOCK DIAGRAM APPROACH

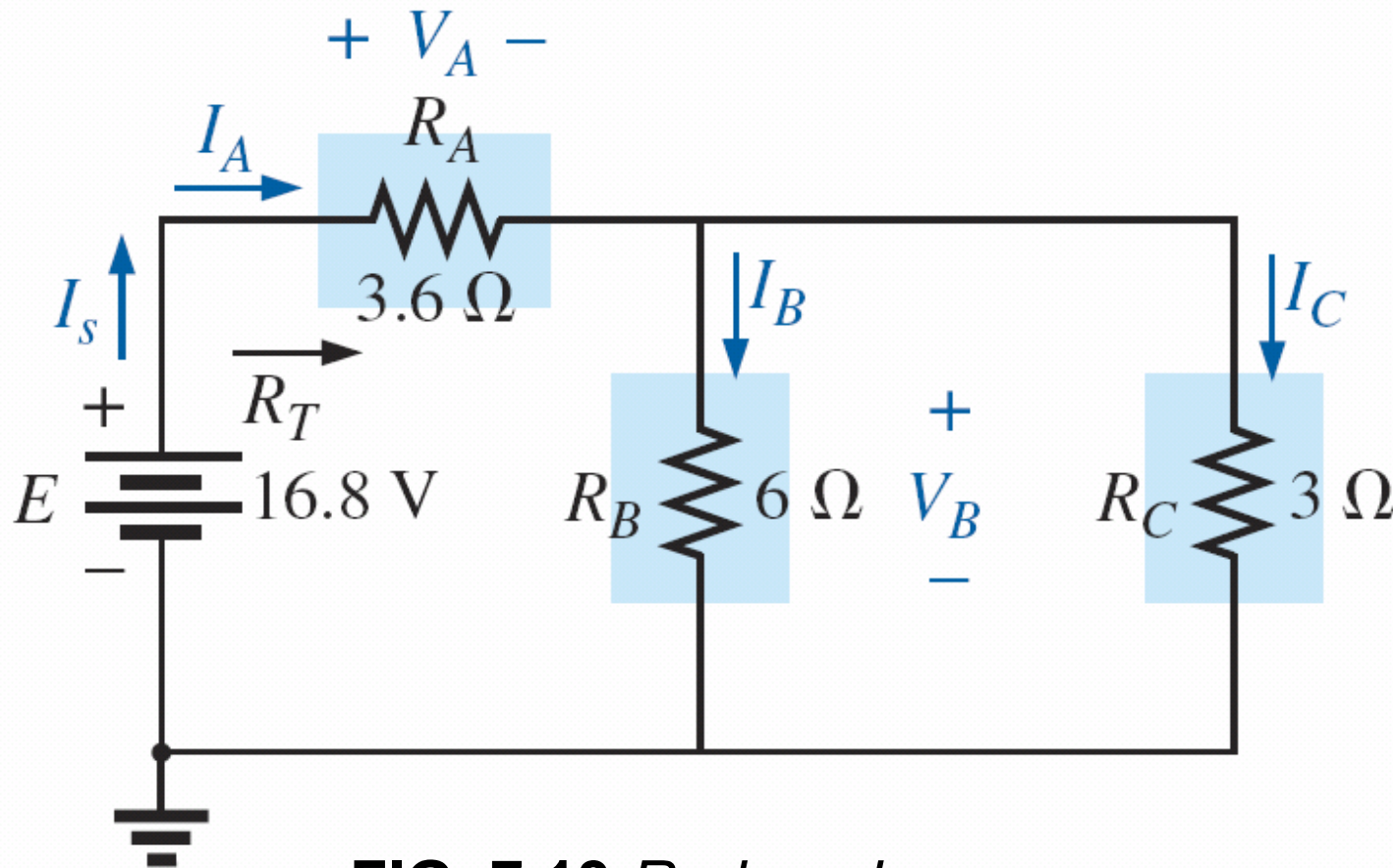


FIG. 7.13 *Reduced equivalent of Fig. 7.12.*

DESCRIPTIVE EXAMPLES

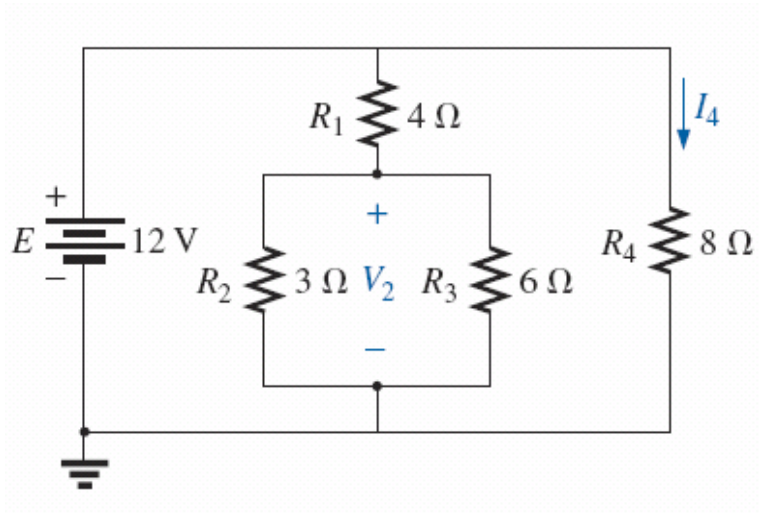


FIG. 7.14
Example 7.5.

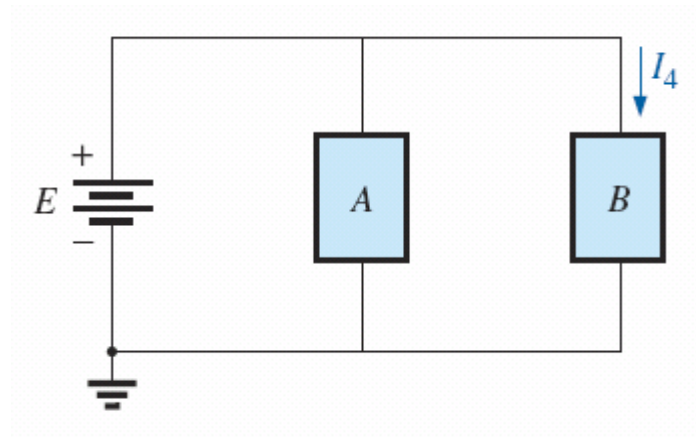


FIG. 7.15 *Block diagram of Fig. 7.14.*

DESCRIPTIVE EXAMPLES

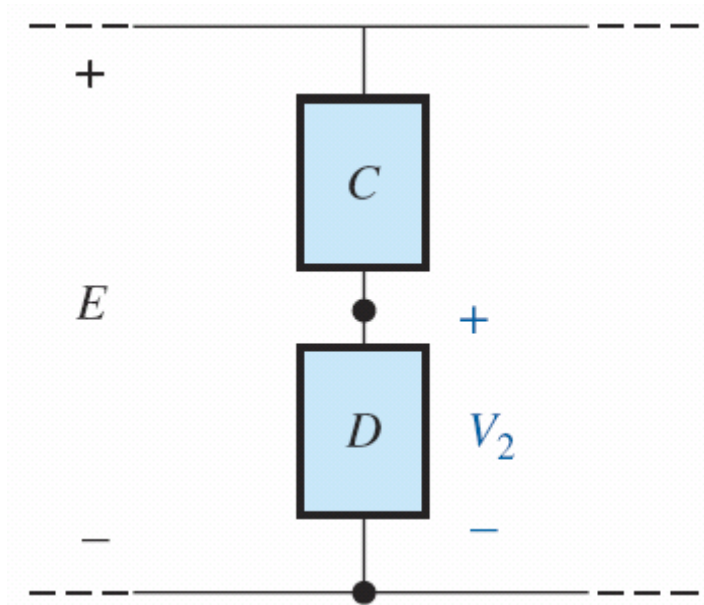


FIG. 7.16 *Alternative block diagram for the first parallel branch in Fig. 7.14.*

DESCRIPTIVE EXAMPLES

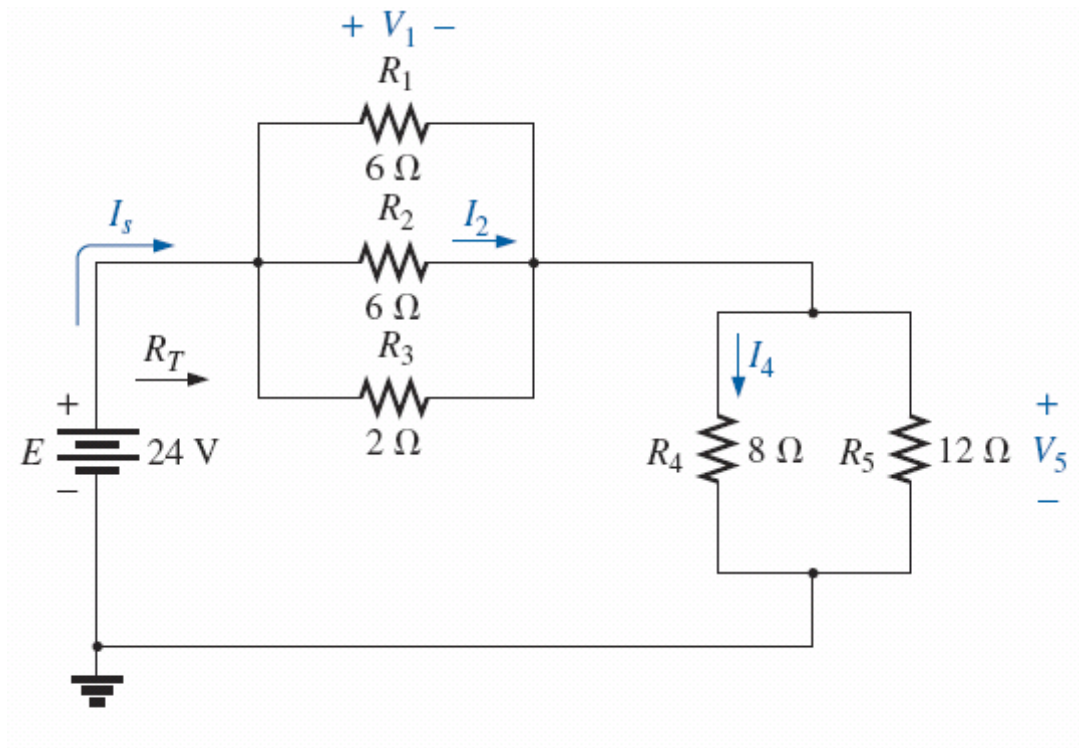


FIG. 7.17
Example 7.6.

DESCRIPTIVE EXAMPLES

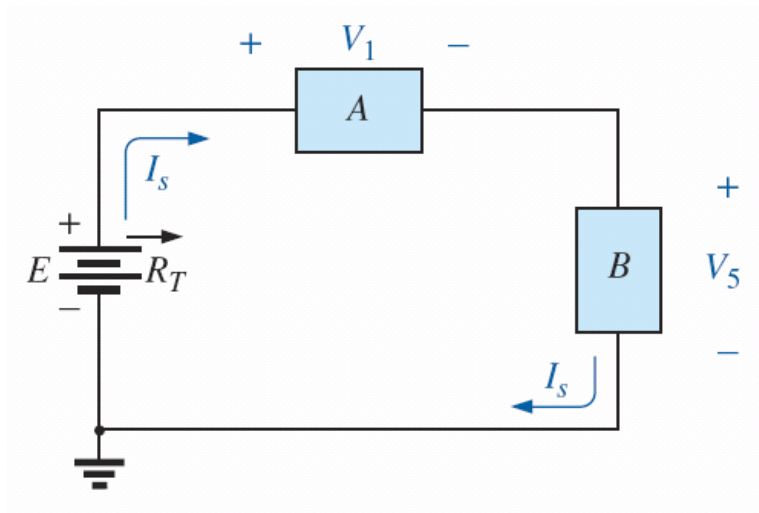


FIG. 7.18 Block diagram for Fig. 7.17.

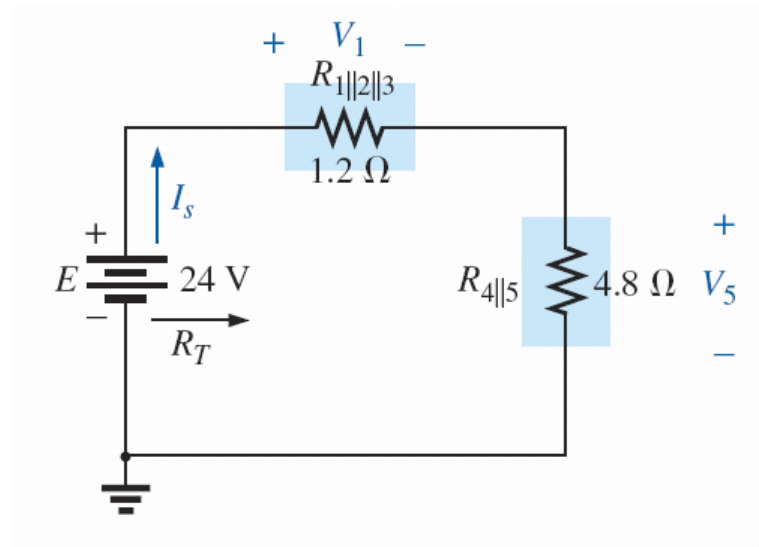


FIG. 7.19
Reduced form of Fig. 7.17.

DESCRIPTIVE EXAMPLES

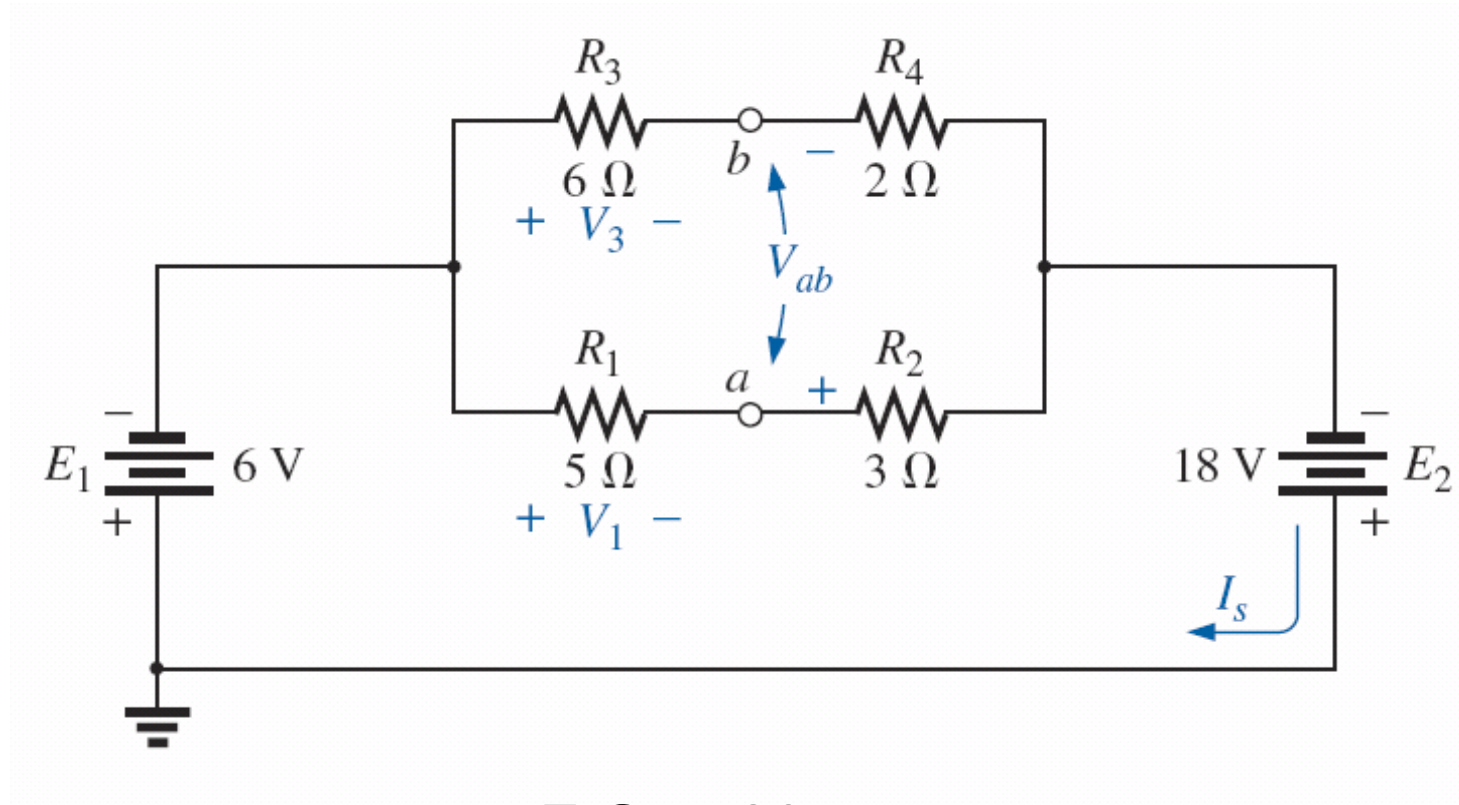


FIG. 7.20
Example 7.7.

DESCRIPTIVE EXAMPLES

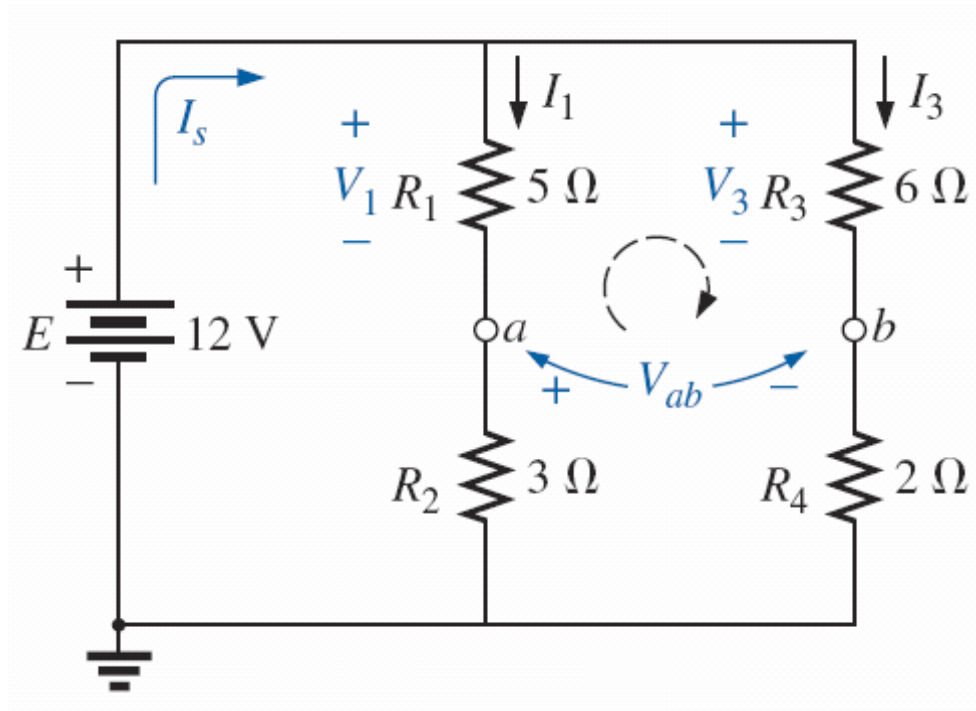


FIG. 7.21 Network in Fig. 7.20 redrawn.

DESCRIPTIVE EXAMPLES

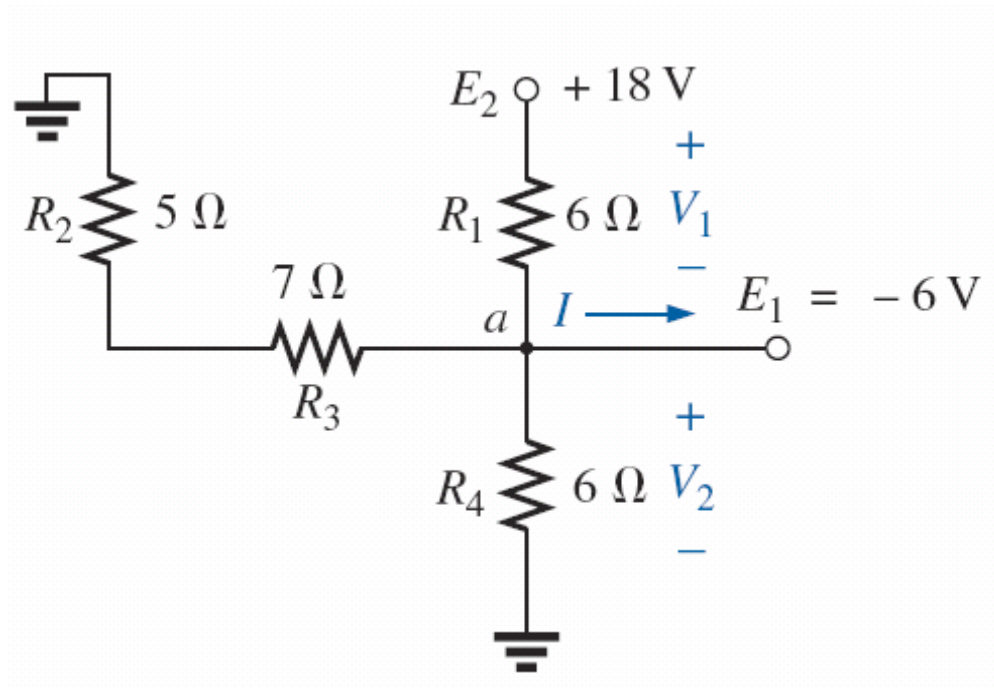


FIG. 7.22
Example 7.8.

DESCRIPTIVE EXAMPLES

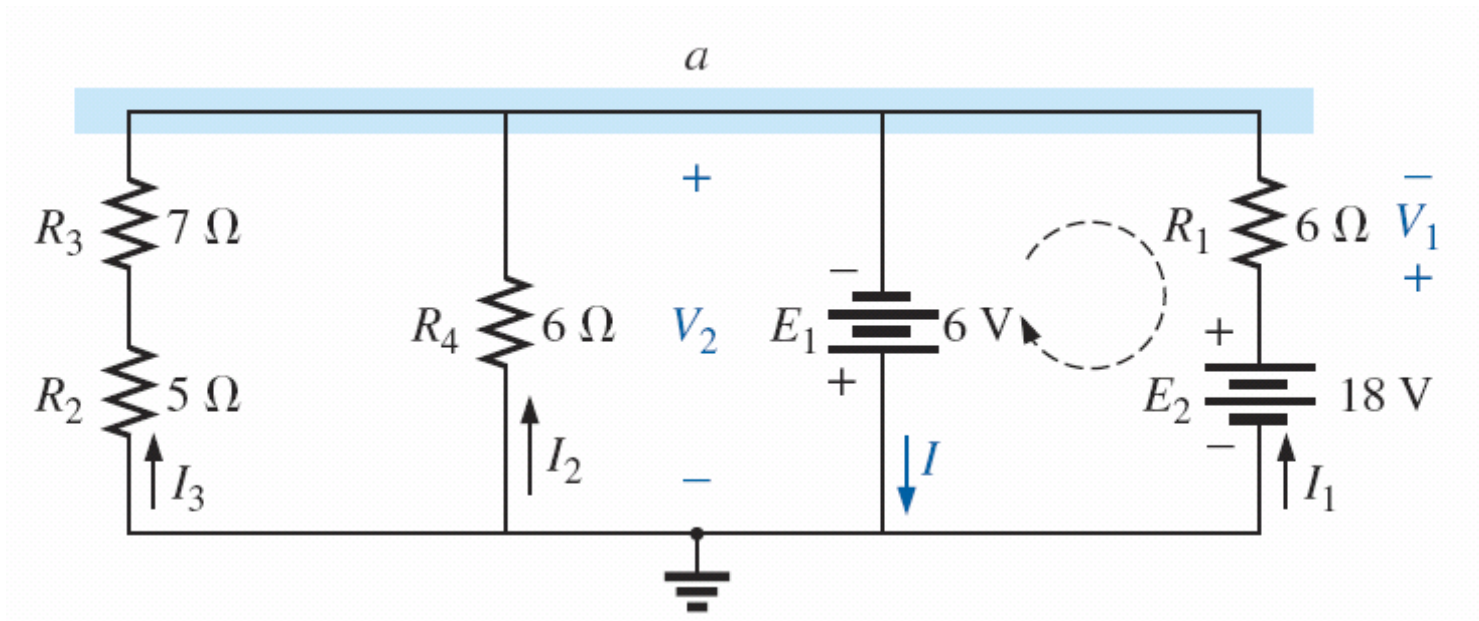


FIG. 7.23 Network in
Fig. 7.22 redrawn.

DESCRIPTIVE EXAMPLES

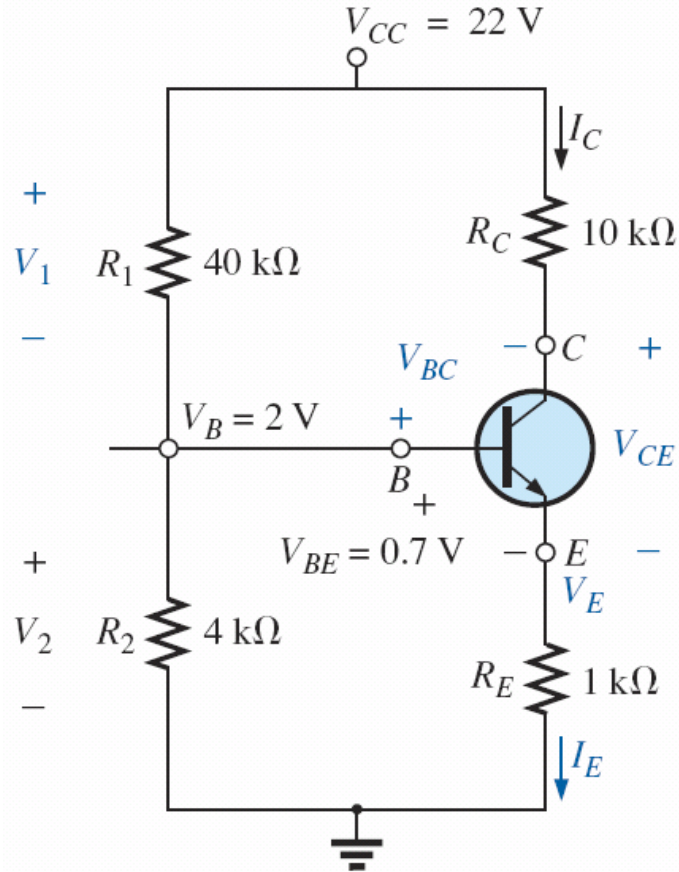


FIG. 7.24
Example 7.9.

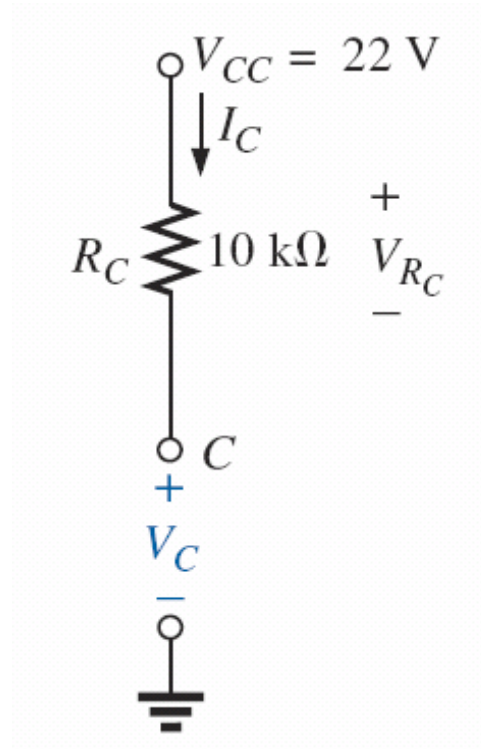


FIG. 7.25 *Determining V_C for the network in Fig. 7.24.*

DESCRIPTIVE EXAMPLES

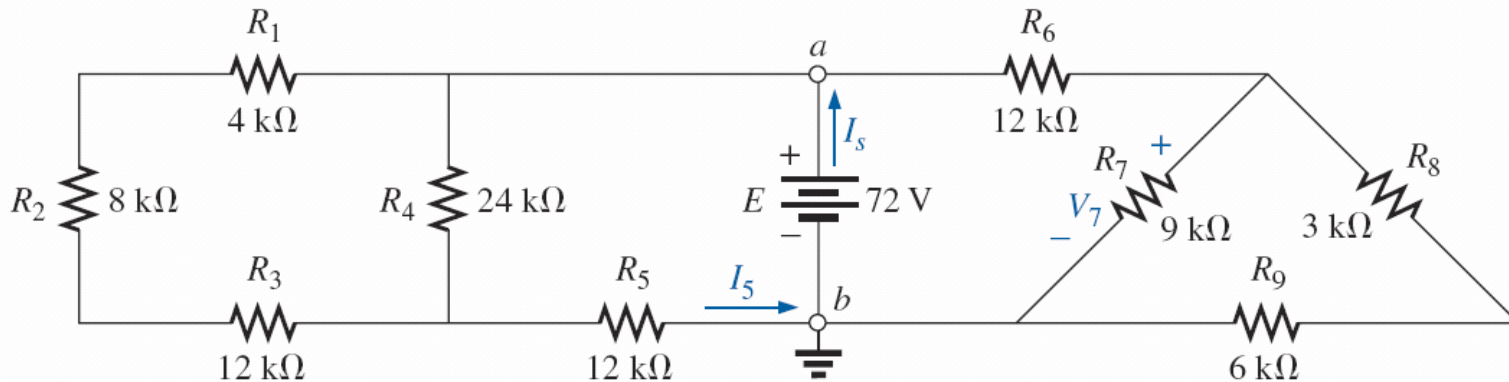


FIG. 7.26
Example 7.10.

DESCRIPTIVE EXAMPLES

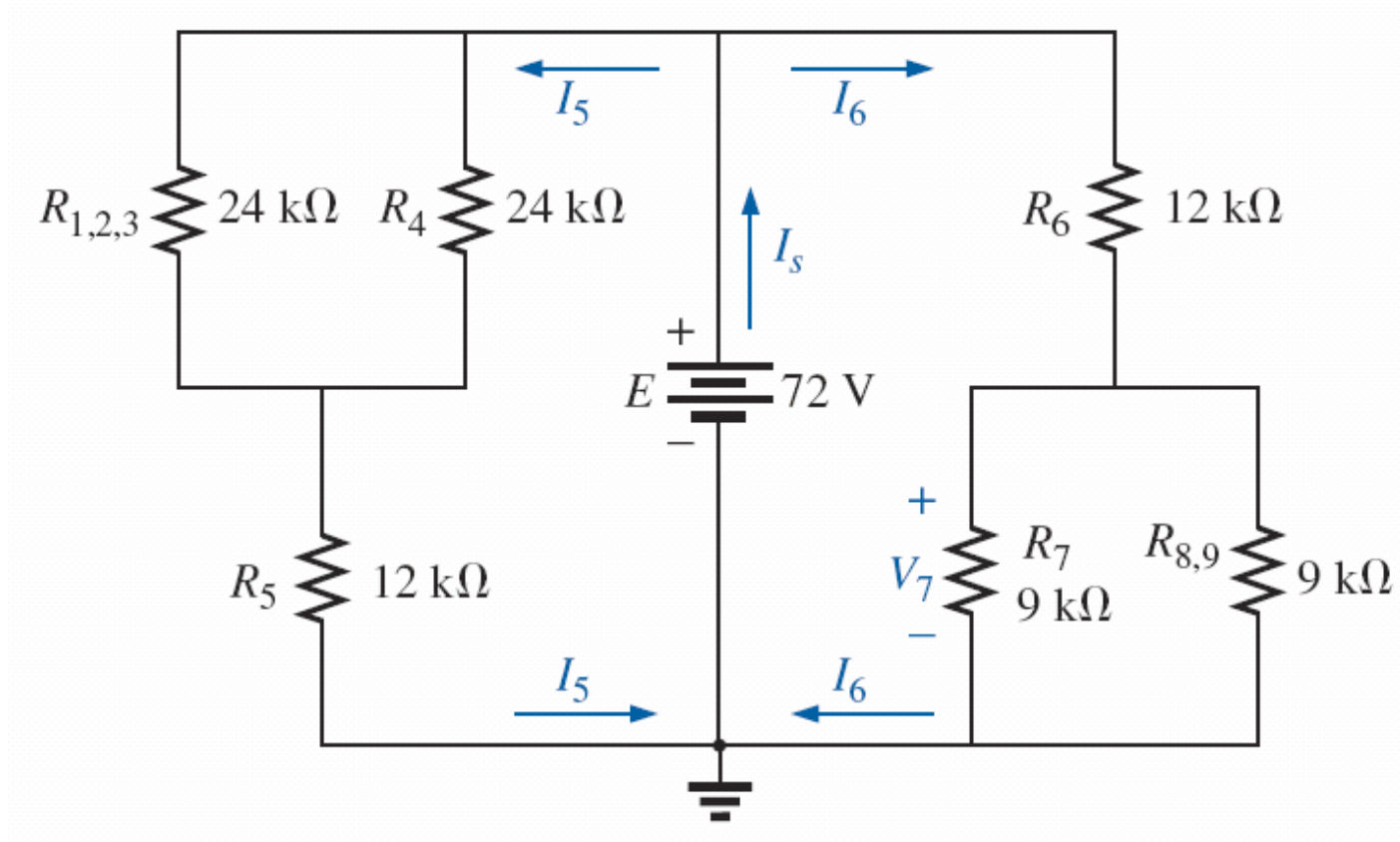


FIG. 7.27 Network in
Fig. 7.26 redrawn.

DESCRIPTIVE EXAMPLES

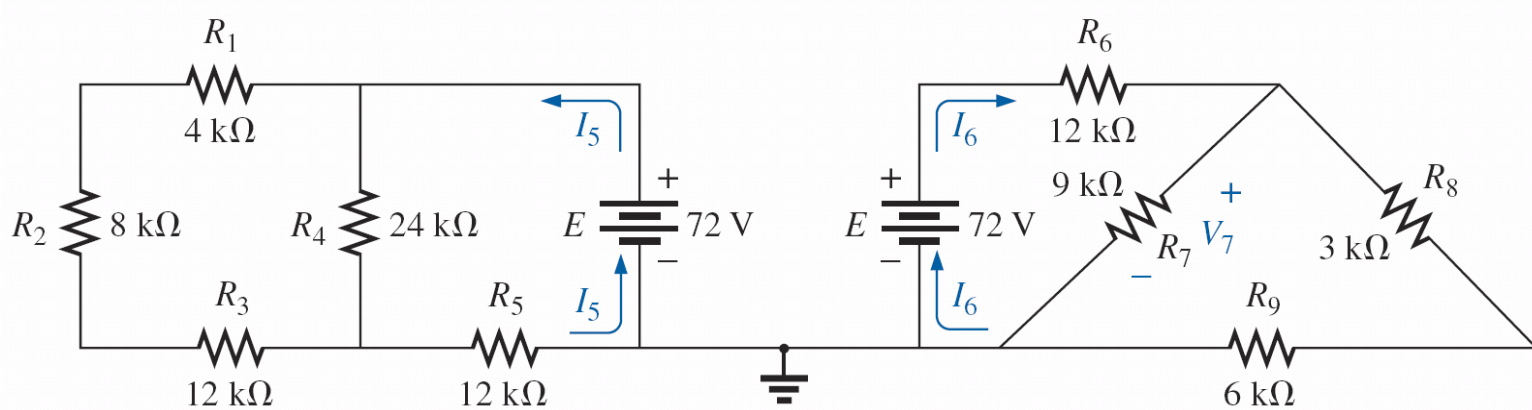


FIG. 7.28 *An alternative approach to Example 7.10.*

DESCRIPTIVE EXAMPLES

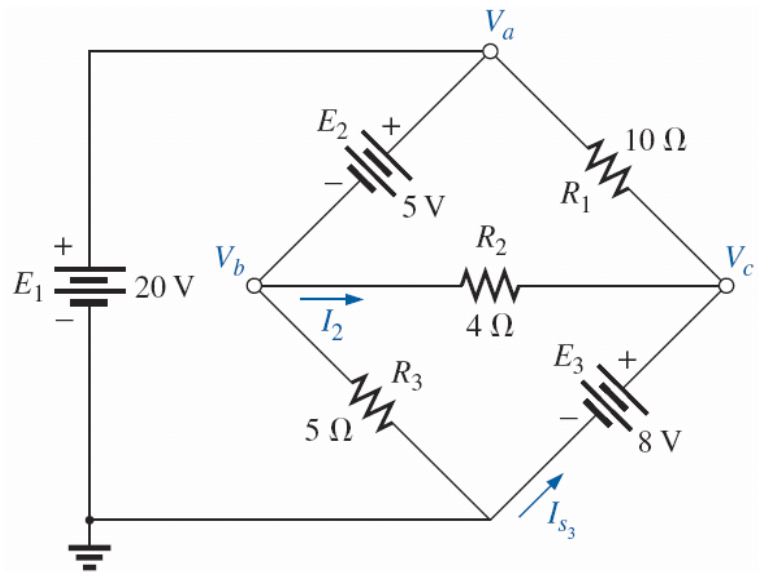


FIG. 7.29
Example 7.11.

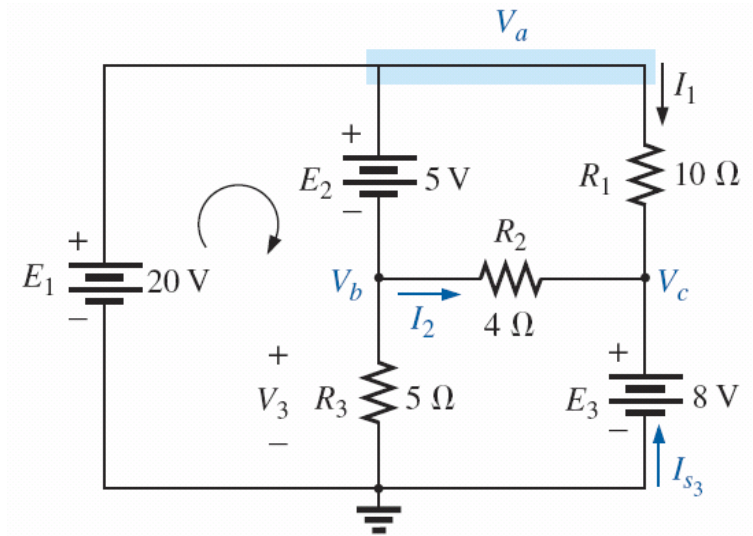


FIG. 7.30 *Network in Fig. 7.29 redrawn to better define a path toward the desired unknowns.*

DESCRIPTIVE EXAMPLES

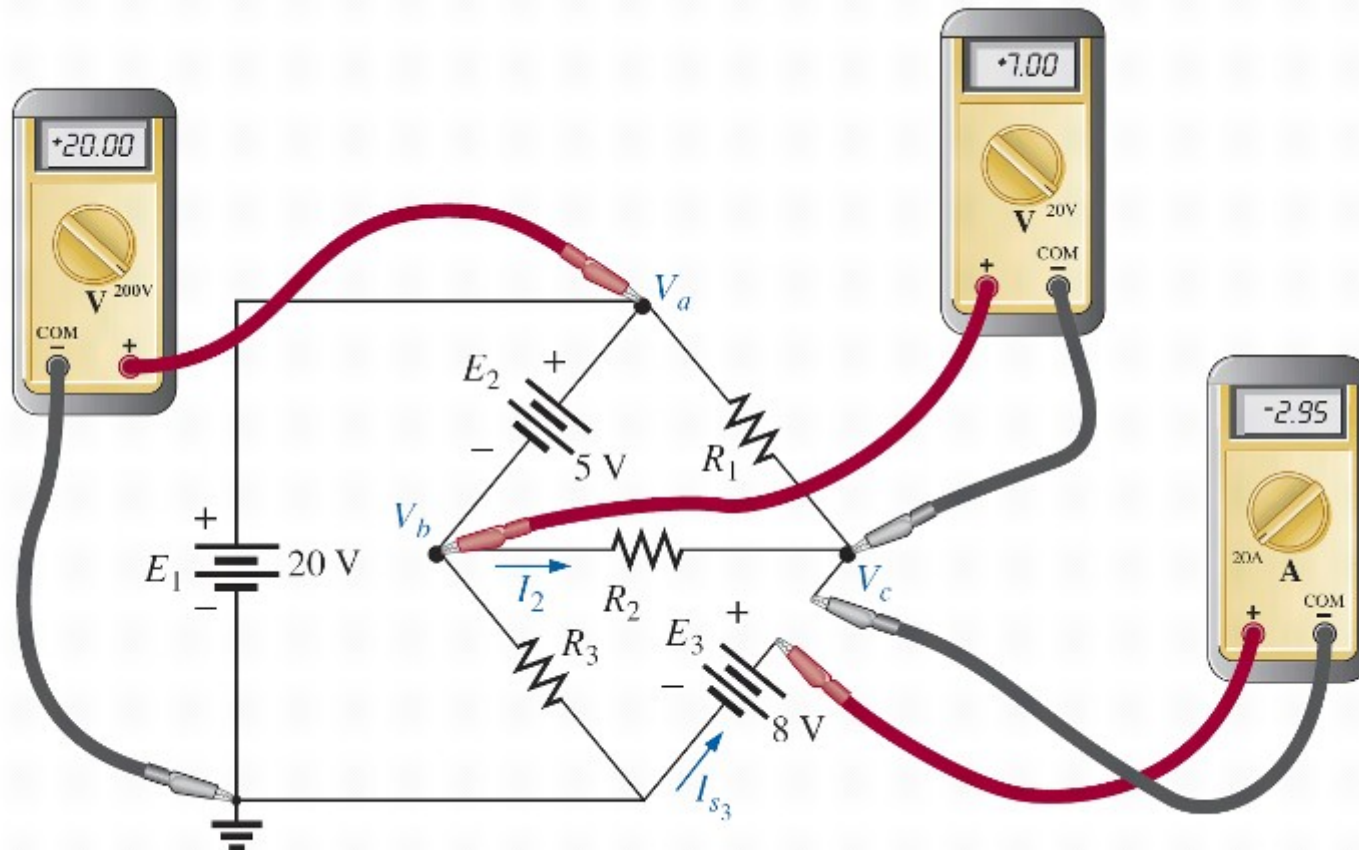


FIG. 7.31 *Complex network for Example 7.11.*

LADDER NETWORKS

- A three-section ladder network appears in Fig. 7.32.
- The reason for the terminology is quite obvious for the repetitive structure.
- Basically two approaches are used to solve networks of this type.

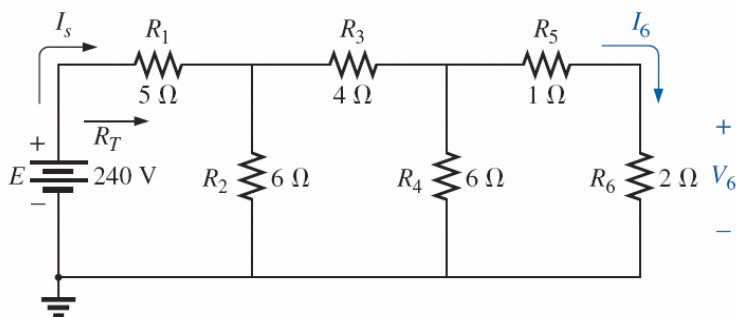


FIG. 7.32
Ladder network.

LADDER NETWORKS

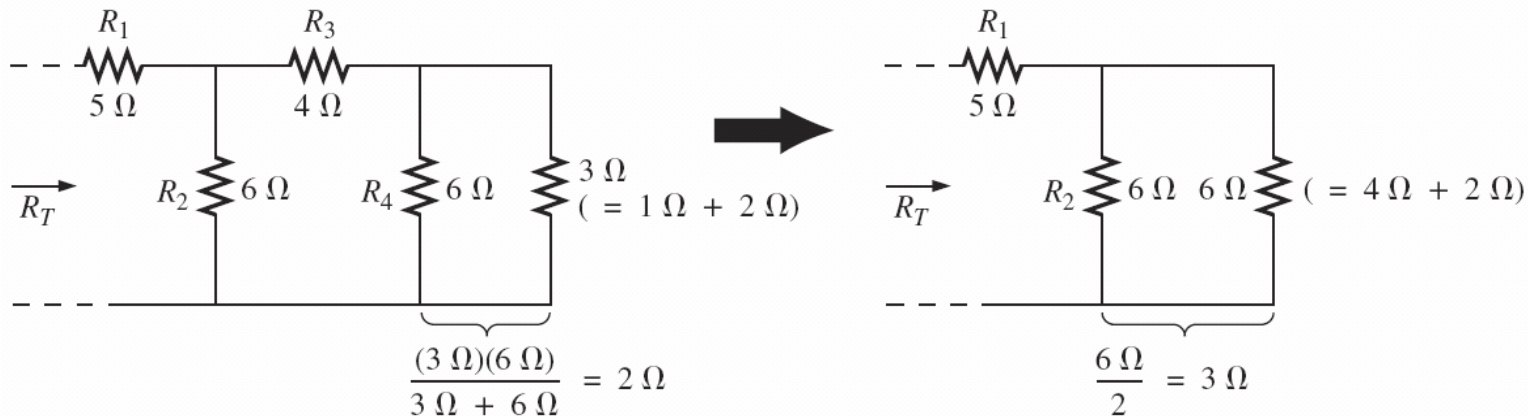


FIG. 7.33 Working back to the source to determine R_T for the network in Fig. 7.32.

LADDER NETWORKS

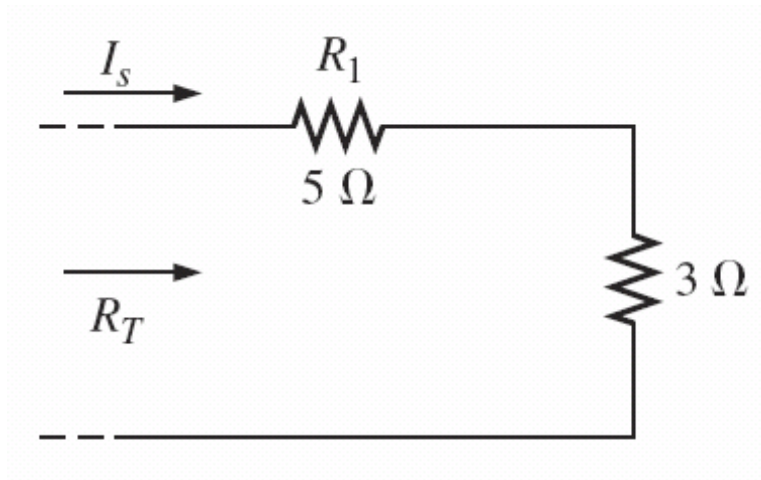


FIG. 7.34
Calculating R_T and I_s .

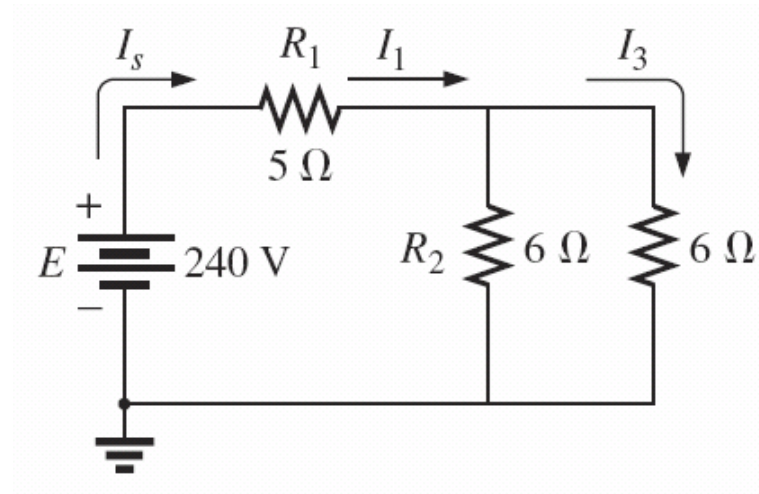


FIG. 7.35 *Working back toward I_6 .*

LADDER NETWORKS

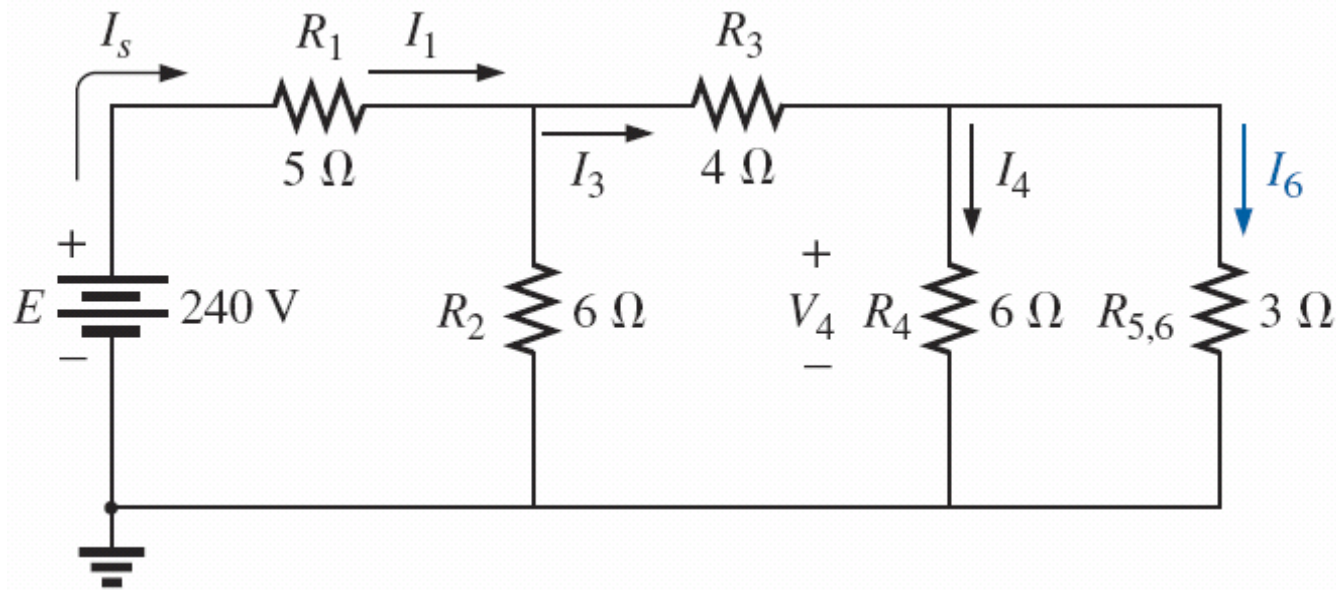


FIG. 7.36
Calculating I_6 .

LADDER NETWORKS

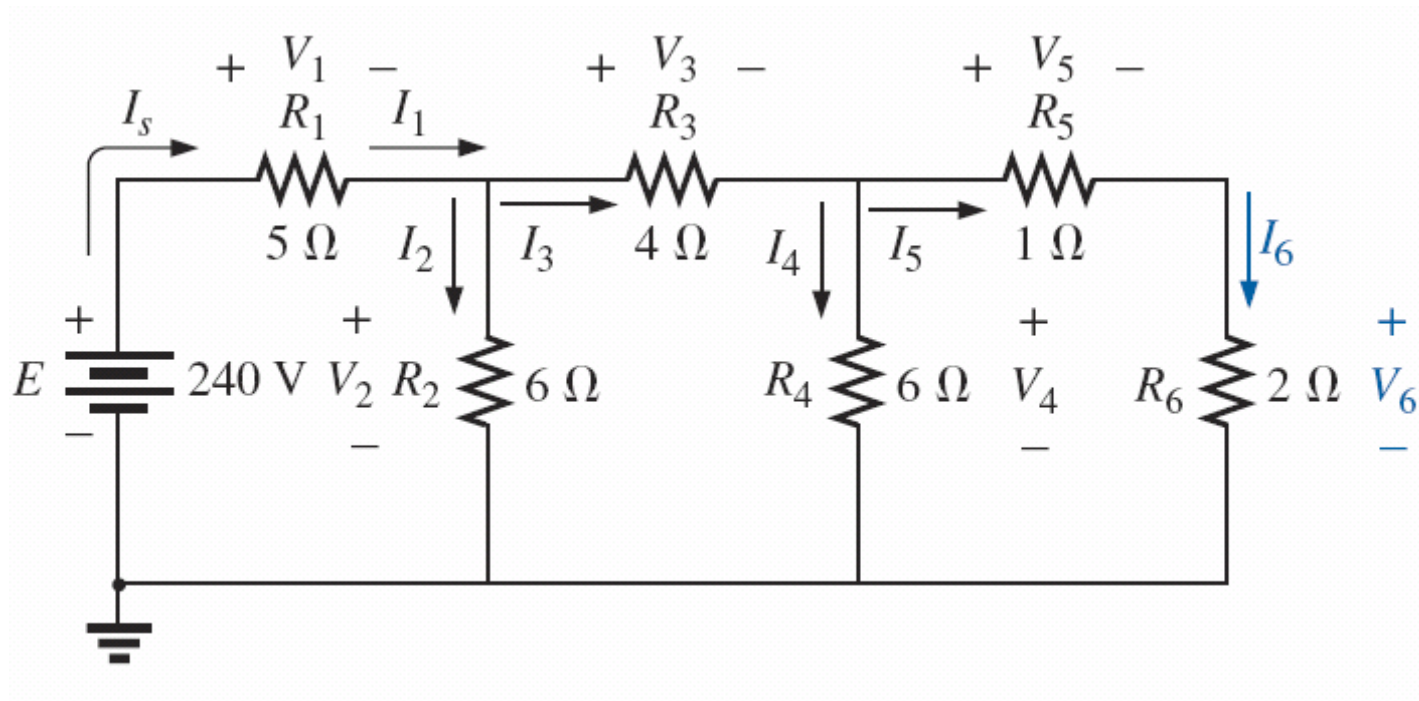


FIG. 7.37 *An alternative approach for ladder networks.*

VOLTAGE DIVIDER SUPPLY (UNLOADED AND LOADED)

- When the term loaded is used to describe voltage divider supply, it refers to the application of an element, network, or system to a supply that draws current from the supply.
 - In other words, the loading down of a system is the process of introducing elements that will draw current from the system. The heavier the current, the greater is the loading effect.

VOLTAGE DIVIDER SUPPLY (UNLOADED AND LOADED)

- No-Load Conditions
 - Through a voltage divider network a number of different terminal voltages can be made available from a single supply.

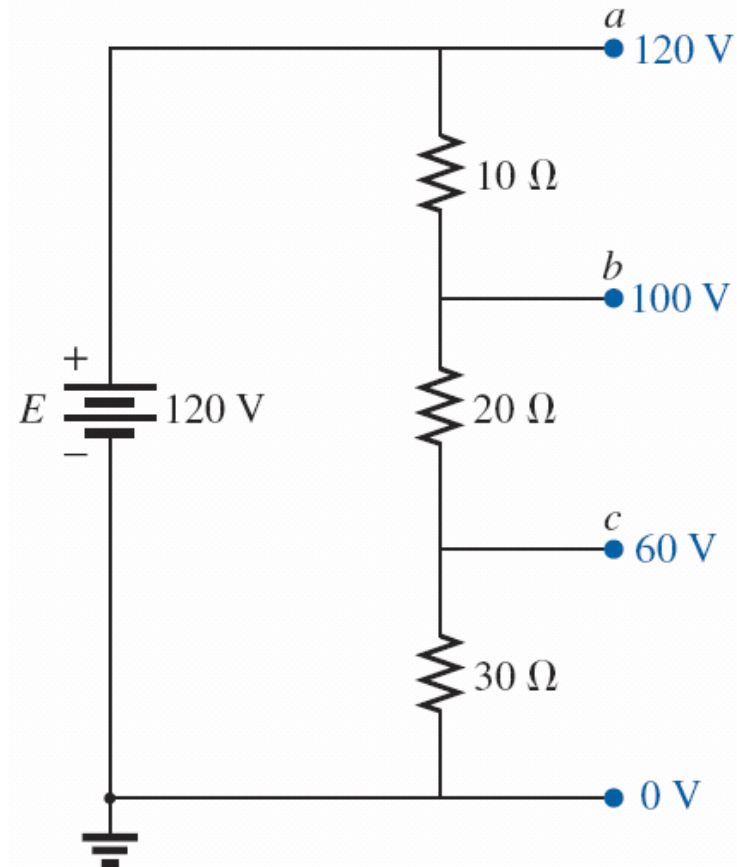


FIG.7.38 *Voltage divider supply.*

VOLTAGE DIVIDER SUPPLY (UNLOADED AND LOADED)

- No-Load Conditions
 - In general, for a voltage divider supply to be effective, the applied resistive loads should be significantly larger than the resistors appearing in the voltage divider network.

VOLTAGE DIVIDER SUPPLY

Loaded Conditions

Voltage divider supply

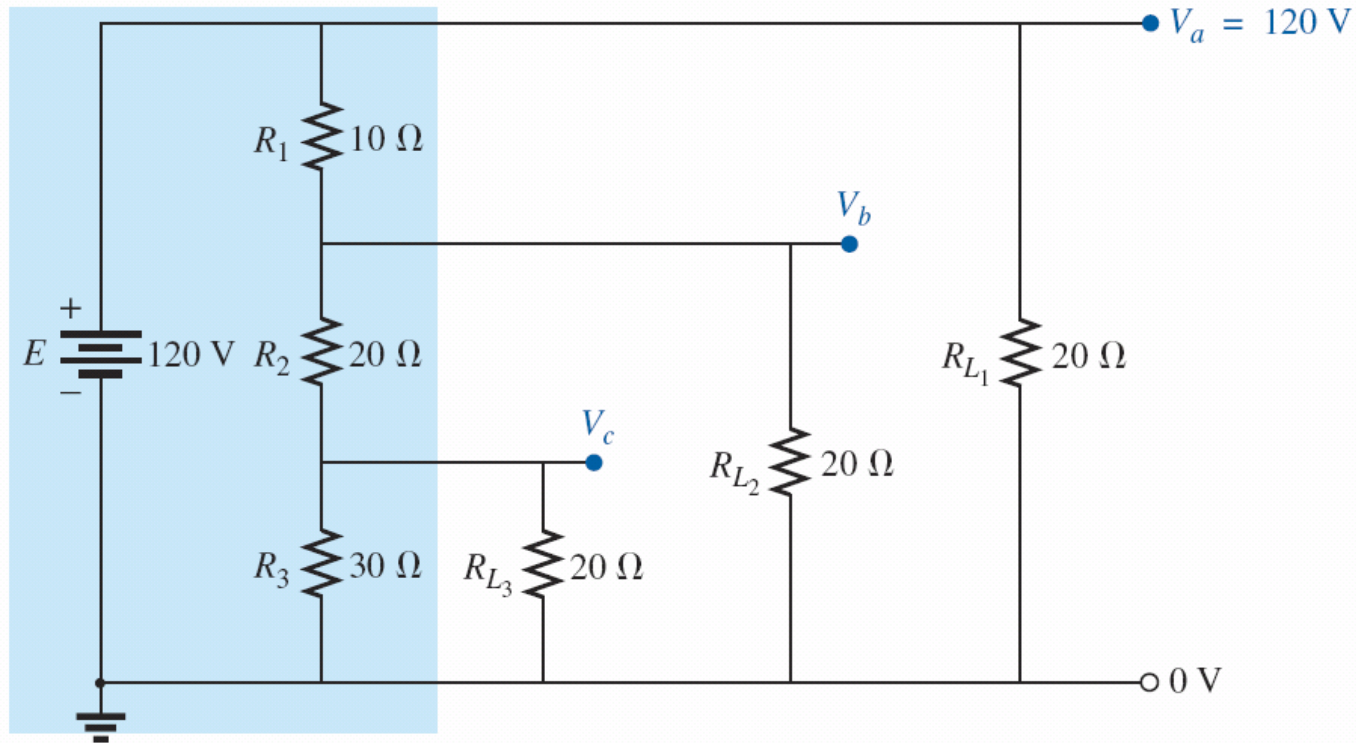


FIG. 7.39 Voltage divider supply with loads equal to the average value of the resistive elements that make up the supply.

VOLTAGE DIVIDER SUPPLY

Loaded Conditions

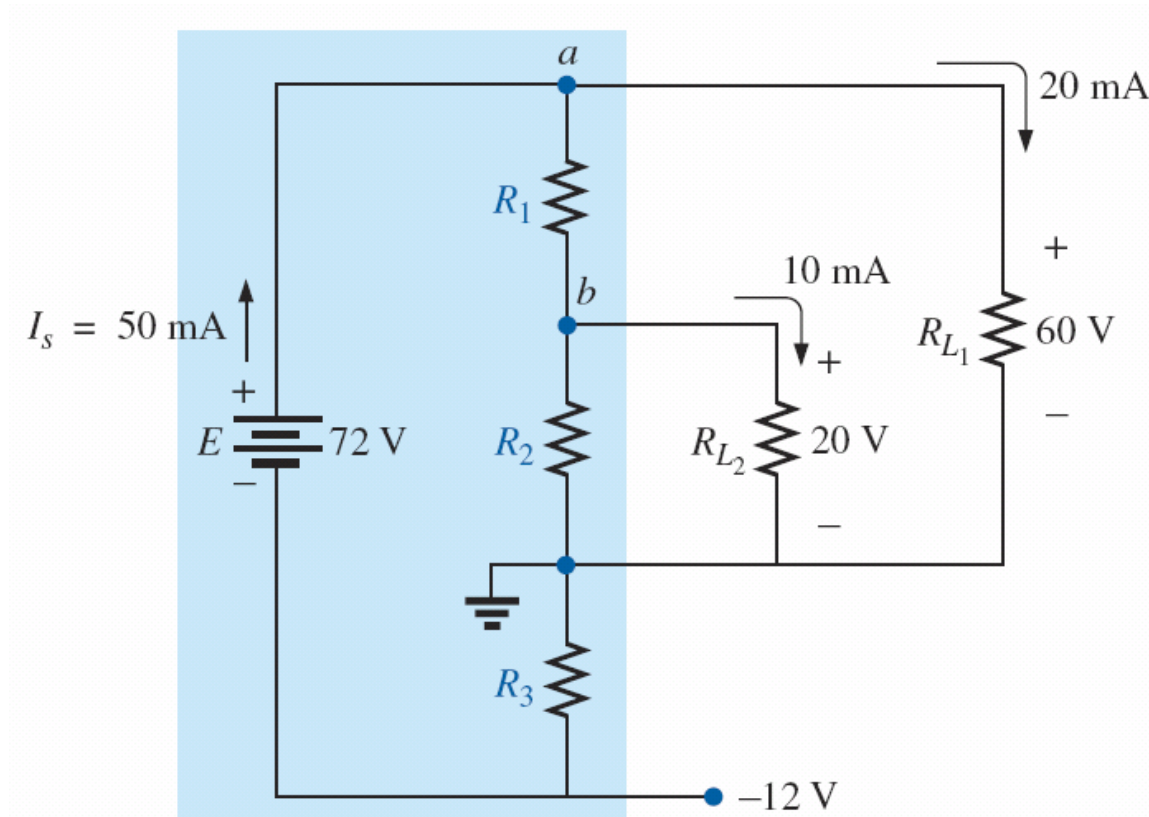


FIG. 7.40 *Voltage divider supply for Example 7.12.*

POTENTIOMETER LOADING

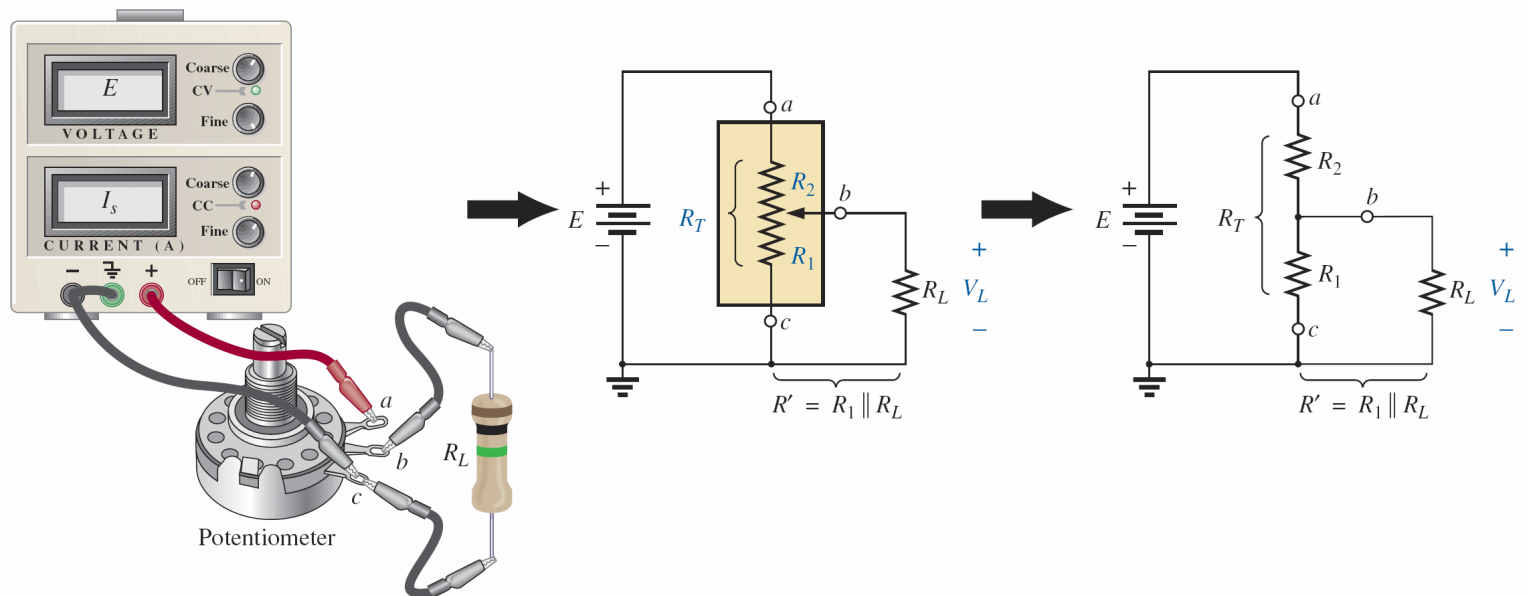


FIG. 7.42 *Loaded potentiometer.*

POTENTIOMETER LOADING

- In general, when hooking up a load to a potentiometer, be sure that the load resistance far exceeds the maximum terminal resistance of the potentiometer if good control of the output voltage is desired.

POTENTIOMETER LOADING

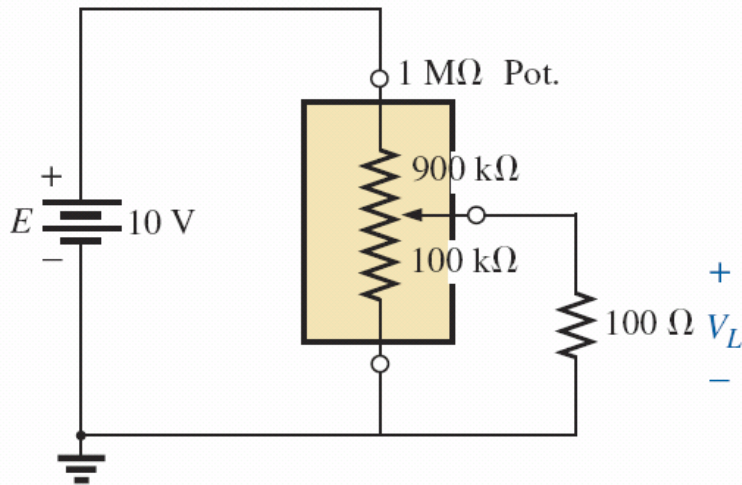


FIG. 7.43 Loaded potentiometer with $R_L \ll R_T$.

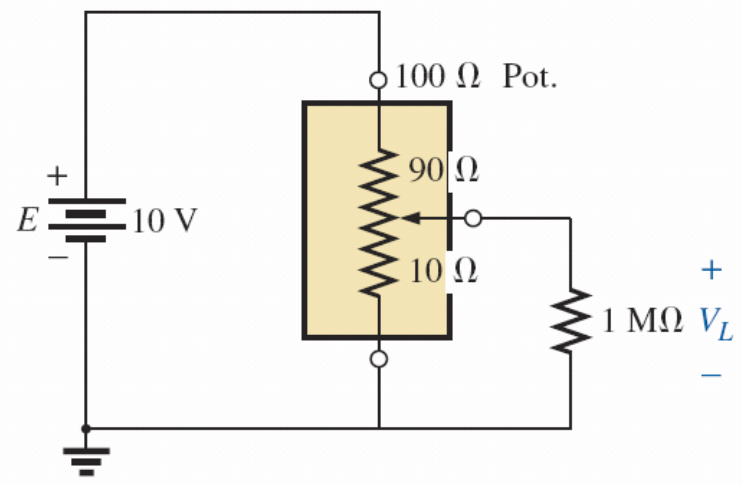


FIG. 7.44 Loaded potentiometer with $R_L \gg R_T$.

POTENTIOMETER LOADING

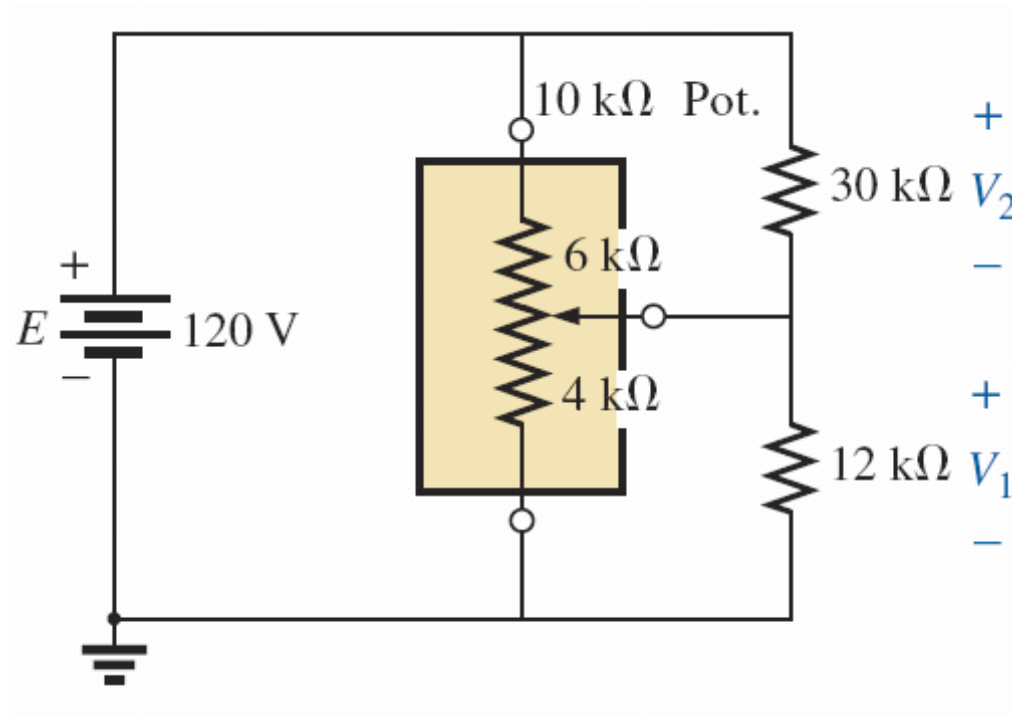


FIG. 7.45
Example 7.13.

IMPACT OF SHORTS AND OPEN CIRCUITS

- Both conditions can wreak havoc on the response of a system. Both are frequently blamed for serious problems in network behavior and often very difficult to find.
 - Trained technicians and engineers develop a sense for finding the root of a problem through the application of common sense developed over the years.

AMMETER, VOLTMETER, AND OHMMETER DESIGN

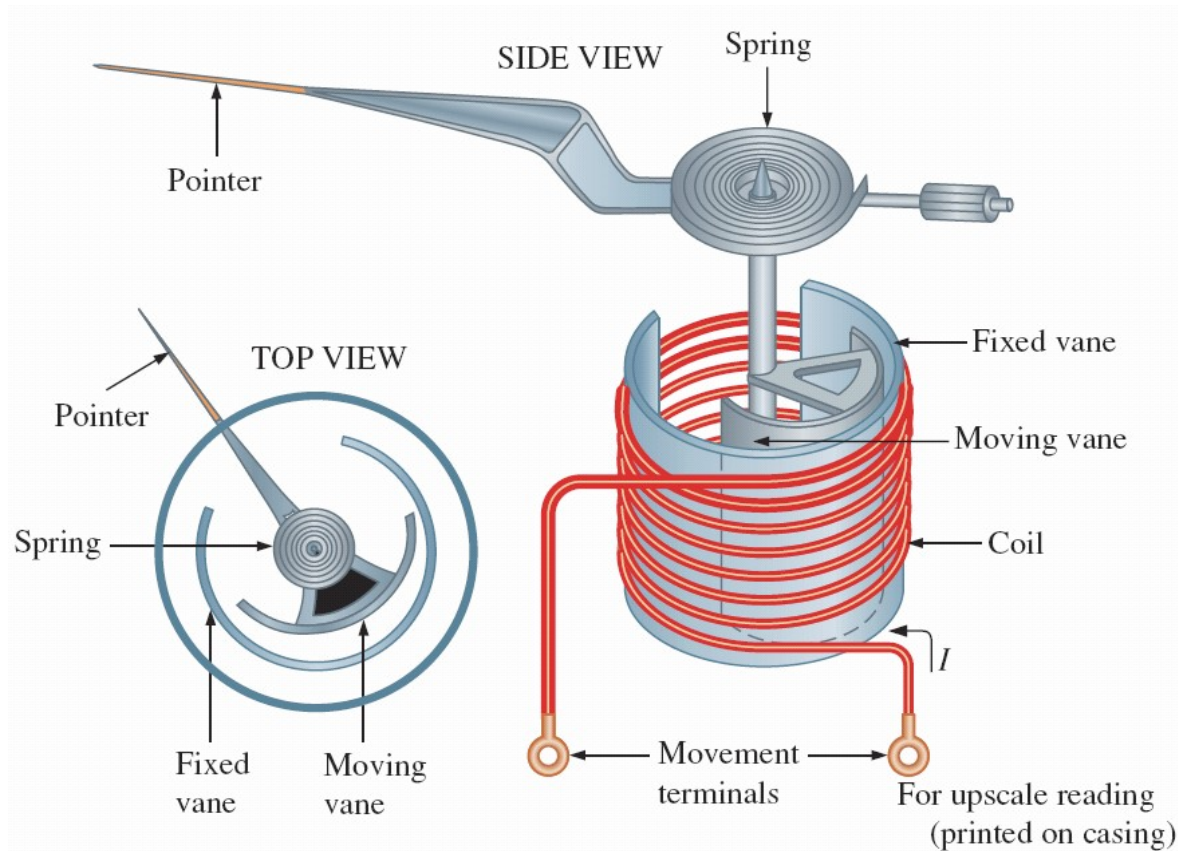


FIG. 7.50 *Iron-vane movement.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

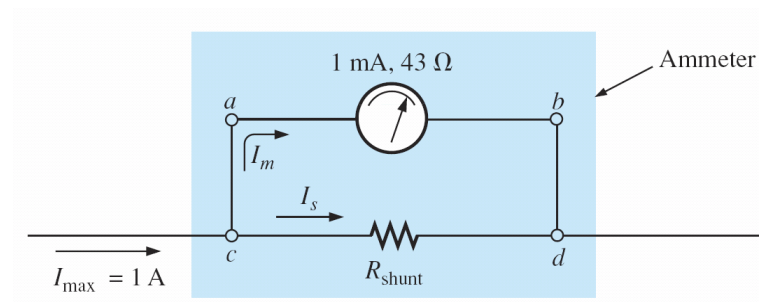
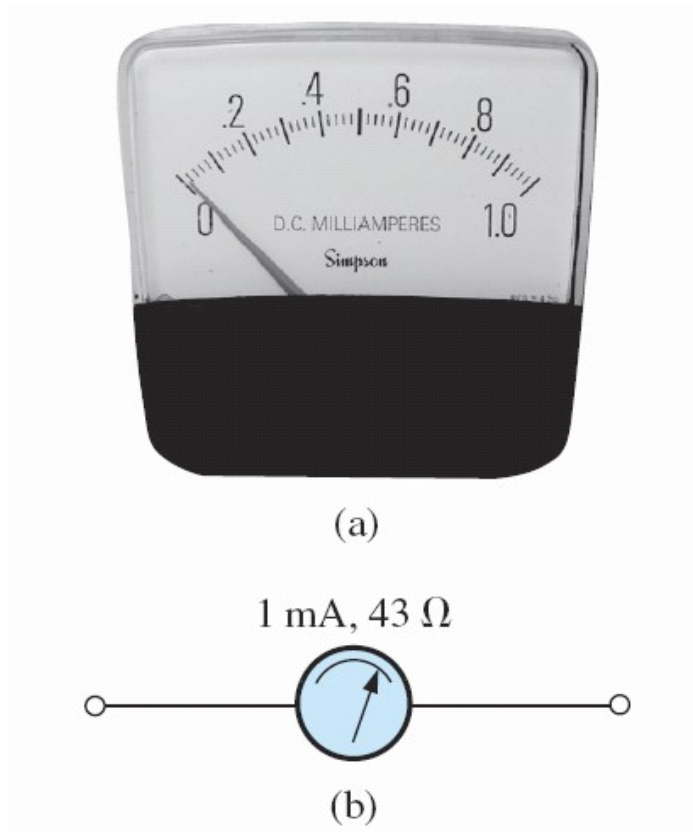


FIG. 7.52

Basic

ammeter.

FIG. 7.51 *Iron-vane movement; (a) photo, (b) symbol and ratings.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

- The Ammeter
 - The maximum current that the iron-vane movement can read independently is equal to the current sensitivity of the movement.
 - Most meters use the same scale for various values of maximum current.
 - If you read 375 on the 0–5 mA scale with the switch on the 5 setting, the current is 3.75 mA; on the 50 setting, the current is 37.5 mA; and so on.

AMMETER, VOLTMETER, AND OHMMETER DESIGN

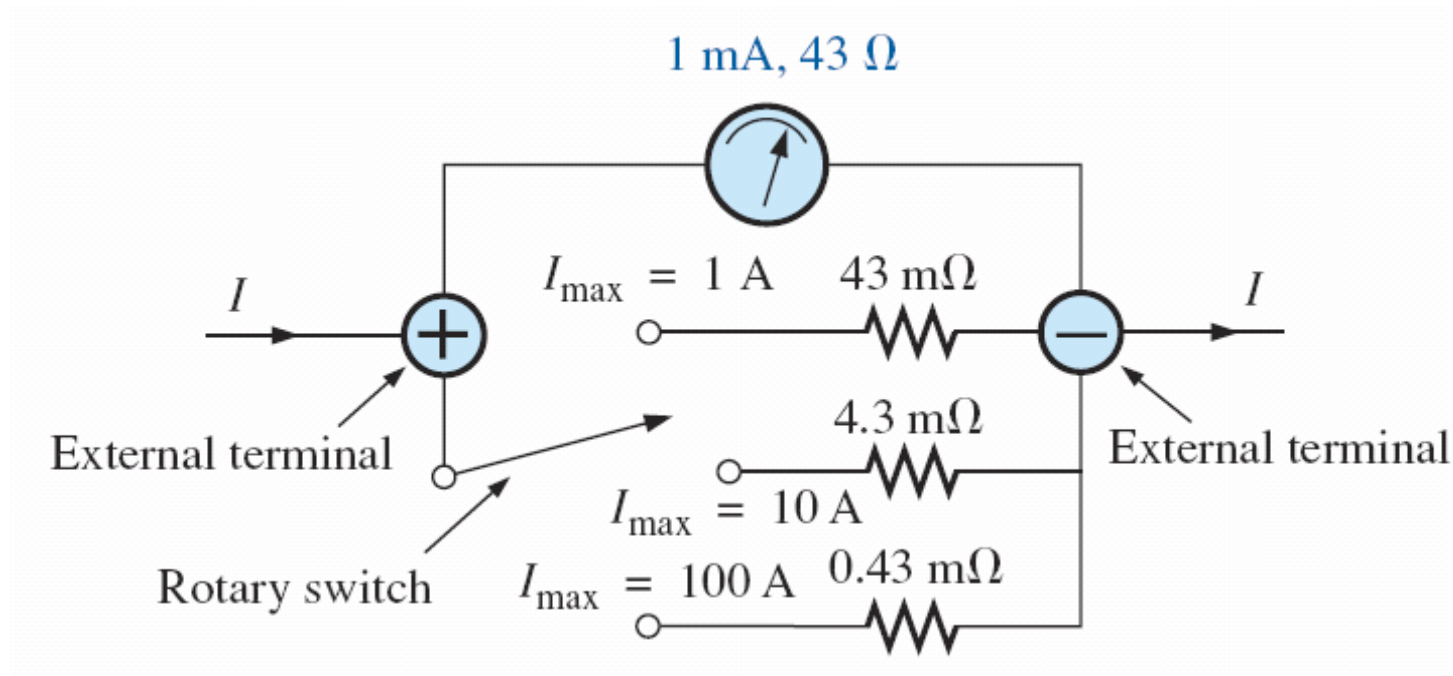


FIG. 7.53
*Multirange
ammeter.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

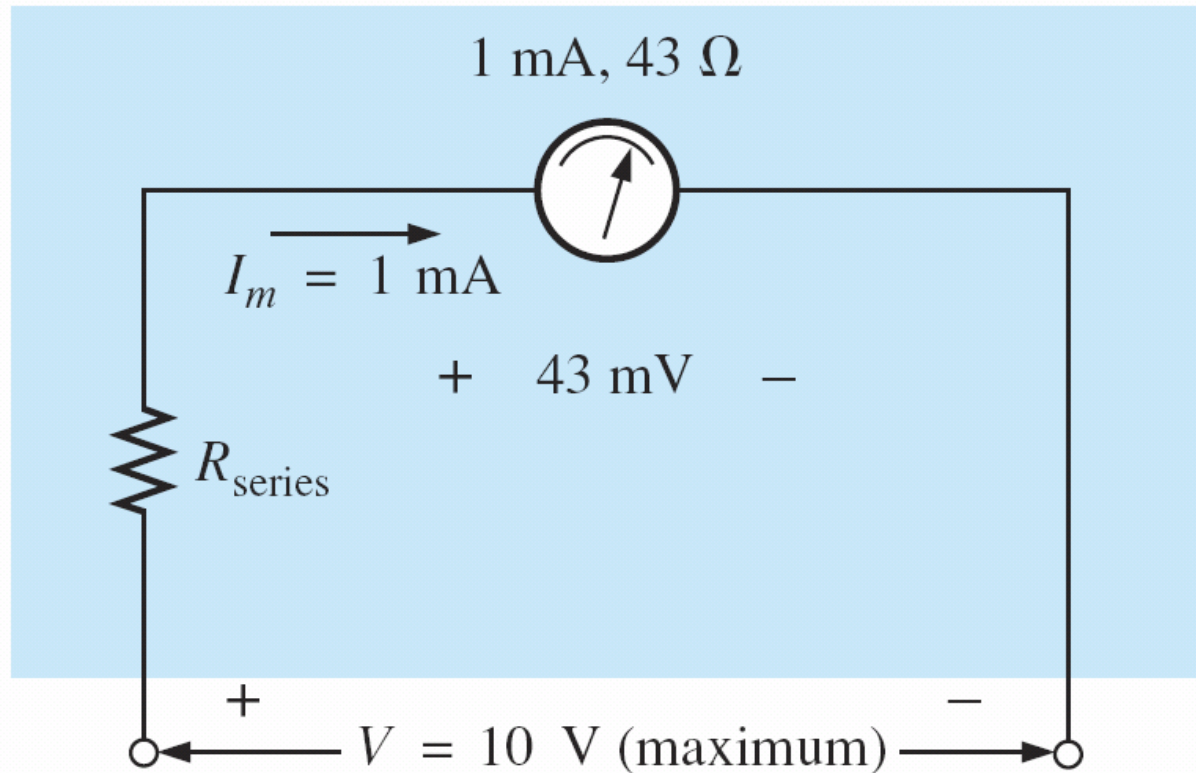


FIG. 7.54 *Basic voltmeter.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

- The Voltmeter
 - A variation in the additional circuitry permits the use of the iron-vane movement in the design of a voltmeter.
 - The 1 mA, 43 Ω movement can also be rated as a 43 mV ($1 \text{ mA} \times 43 \Omega$), 43 movement, indicating that the maximum voltage that the movement can measure independently is 43 mV.

AMMETER, VOLTMETER, AND OHMMETER DESIGN

- The millivolt rating is sometimes referred to as the voltage sensitivity (VS).

AMMETER, VOLTMETER, AND OHMMETER DESIGN

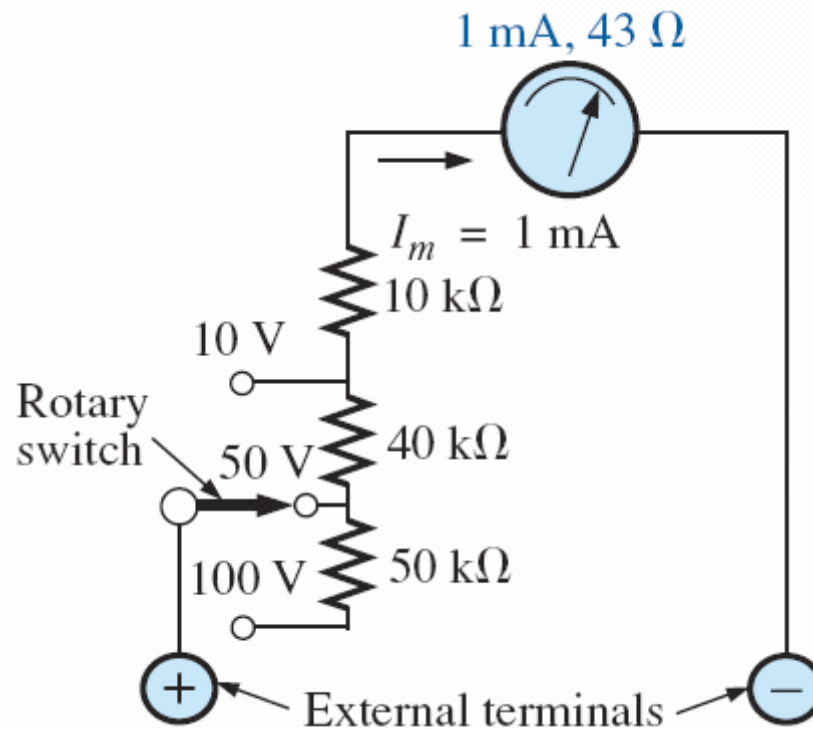


FIG. 7.55
*Multirange
voltmeter.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN

- The Ohmmeter
 - In general, ohmmeters are designed to measure resistance in the low, middle, or high range.
 - The most common is the series ohmmeter, designed to read resistance levels in the midrange.

AMMETER, VOLTMETER, AND OHMMETER DESIGN

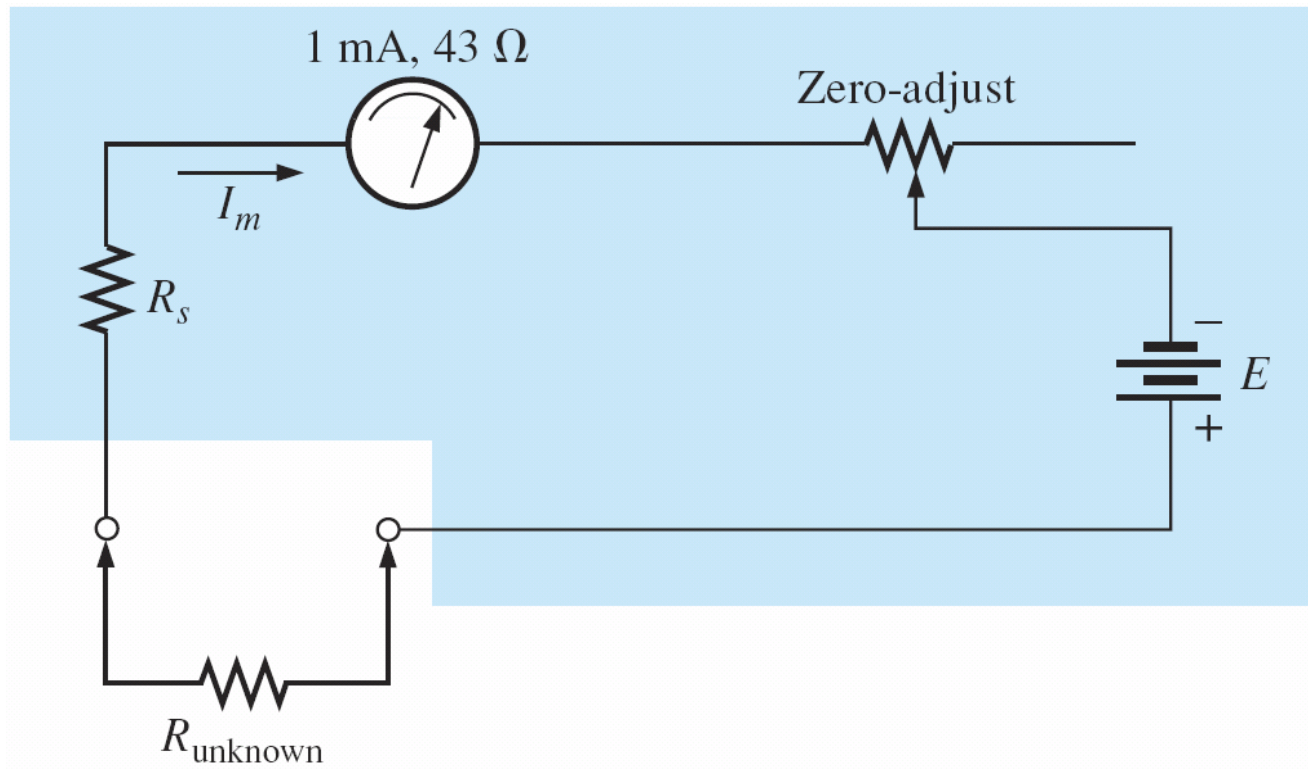


FIG. 7.56 *Series ohmmeter.*

AMMETER, VOLTMETER, AND OHMMETER DESIGN



FIG. 7.57
Nanovoltmeter.

AMMETER, VOLTMETER, AND OHMMETER DESIGN

- The Ohmmeter
 - The megohmmeter (often called megger) is an instrument for measuring very high resistance values.
 - Its primary function is to test the insulation found in power transmission systems, electrical machinery, transformers, and so on.

To measure the high-resistance values, a high dc voltage is established by a hand-driven generator.

AMMETER, VOLTMETER, AND OHMMETER DESIGN



FIG. 7.58
Megohmmeter.

APPLICATIONS

Boosting a Car Battery

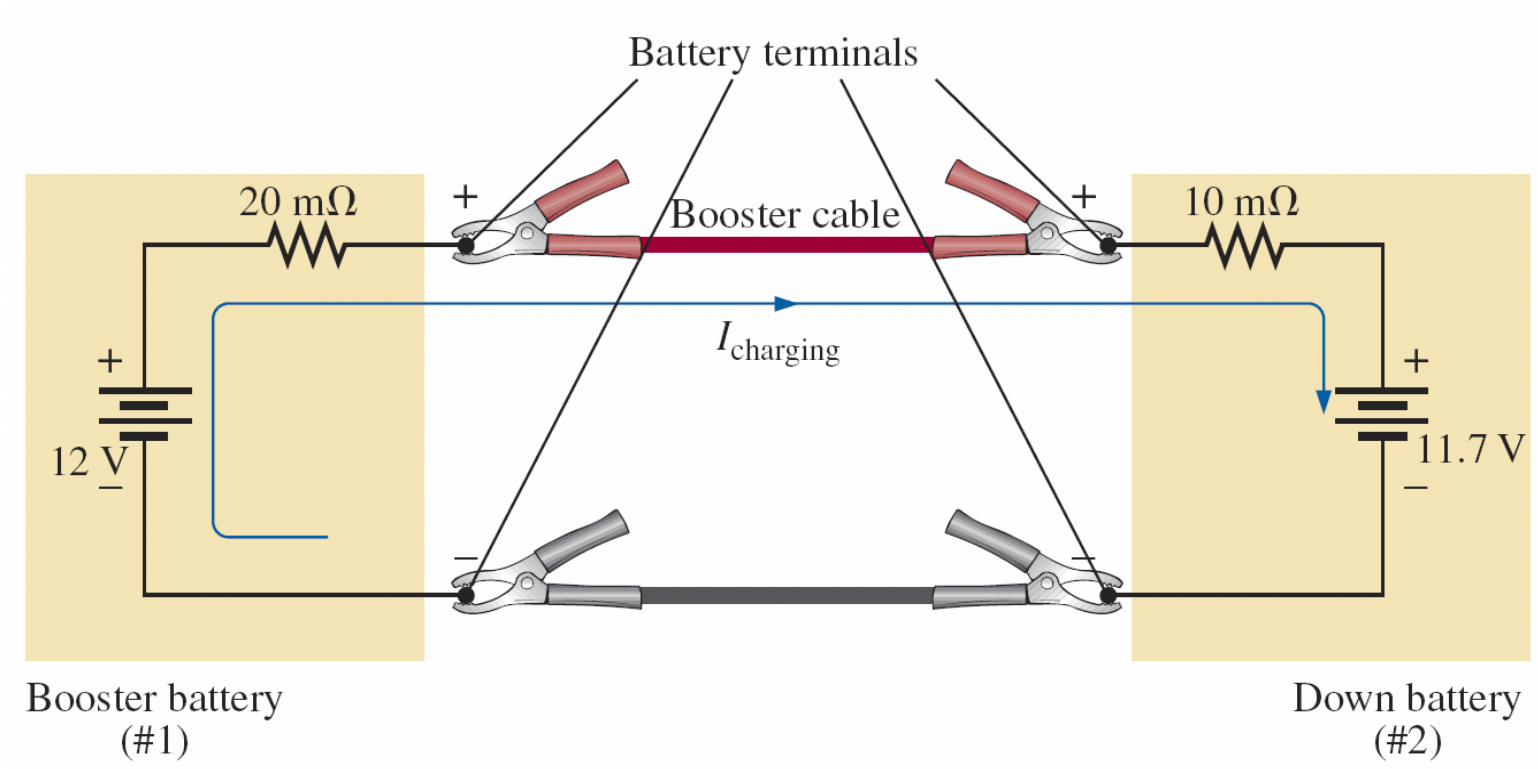


FIG. 7.59 *Boosting a car battery.*

APPLICATIONS

Boosting a Car Battery

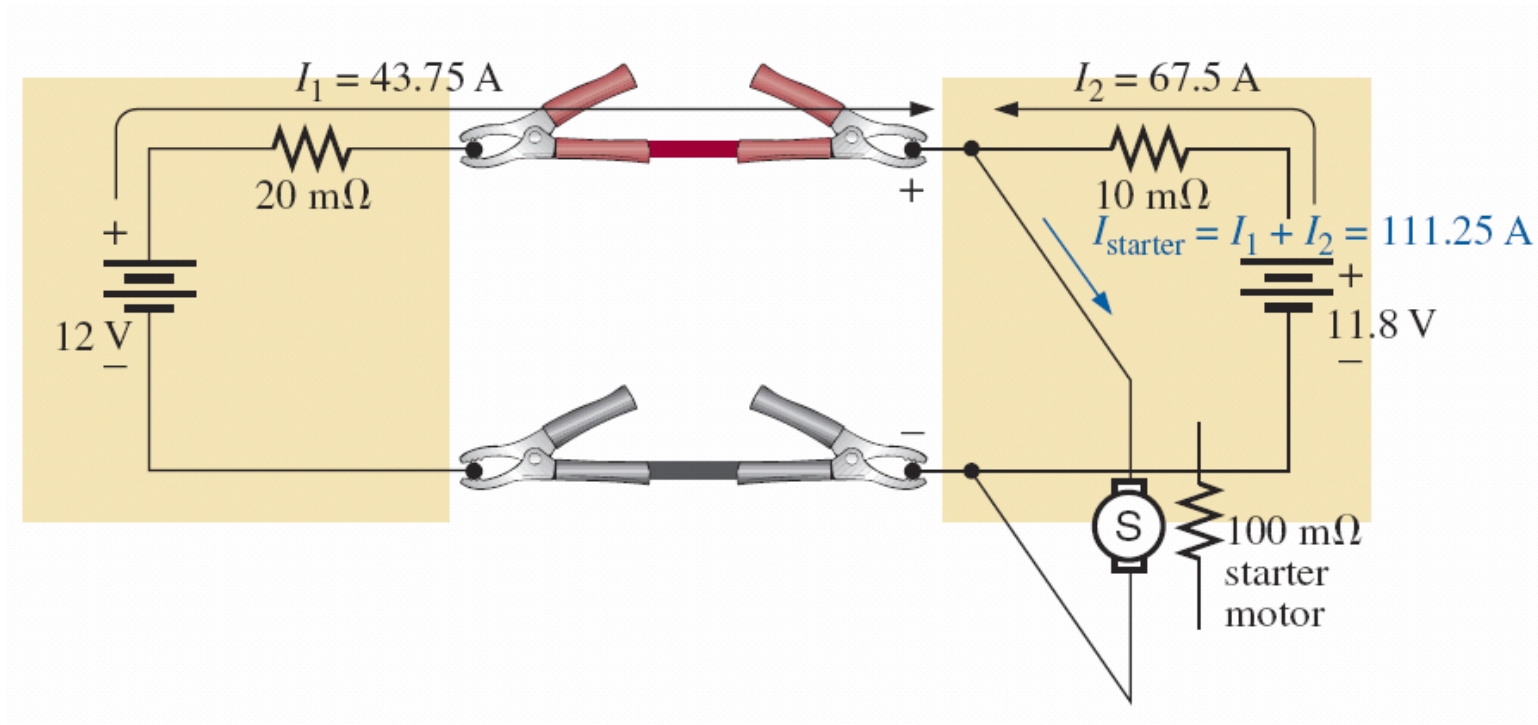


FIG. 7.60 *Current levels at starting.*

APPLICATIONS

Boosting a Car Battery

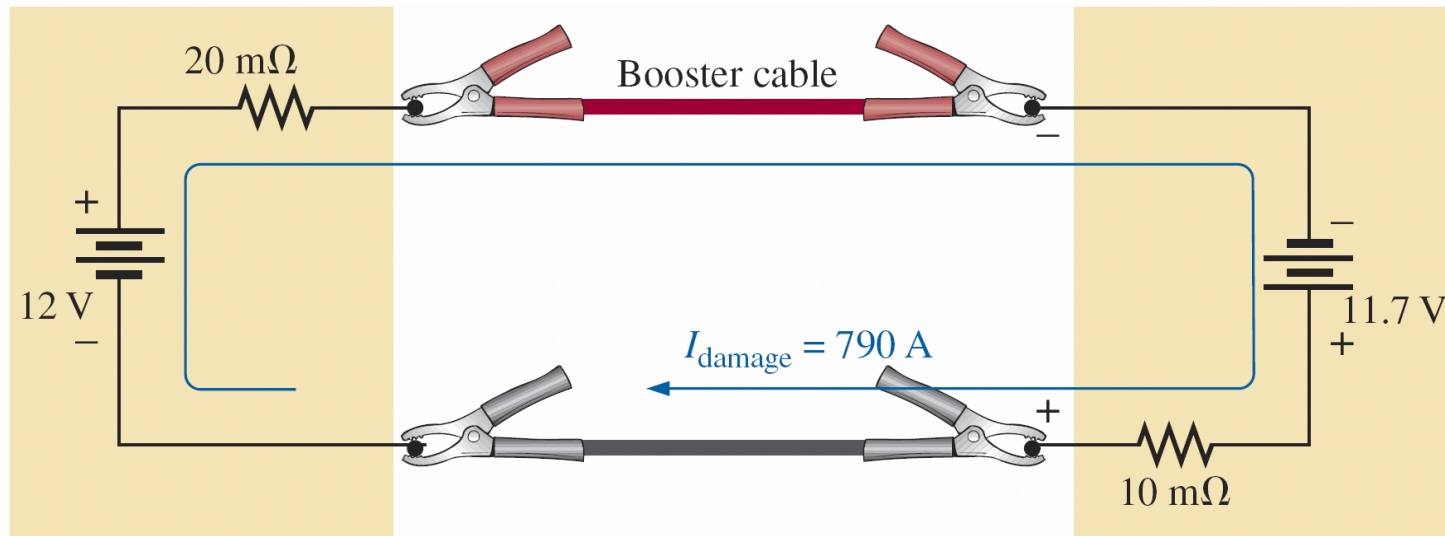


FIG. 7.61 *Current levels if the booster battery is improperly connected.*

APPLICATIONS

Electronic Circuits

- The operation of most electronic systems requires a distribution of dc voltages throughout the design.
- Although a full explanation of why the dc level is required (since it is an ac signal to be amplified) will have to wait for the introductory courses in electronic circuits, the dc analysis will proceed in much the same manner as described in this chapter.

APPLICATIONS

Electronic Circuits

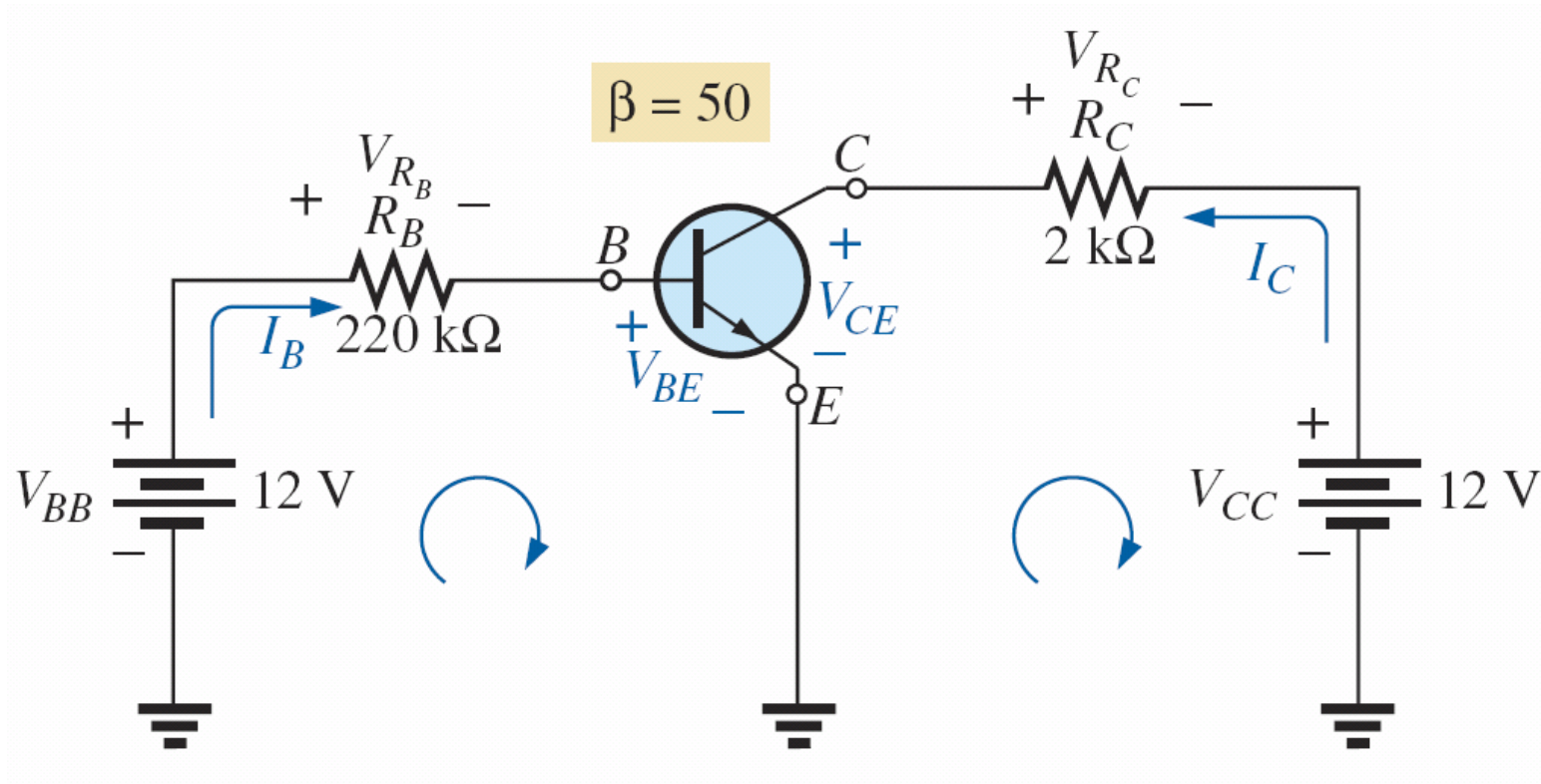


FIG. 7.52 *The dc bias levels of a transistor amplifier.*

COMPUTER ANALYSIS

PSpice

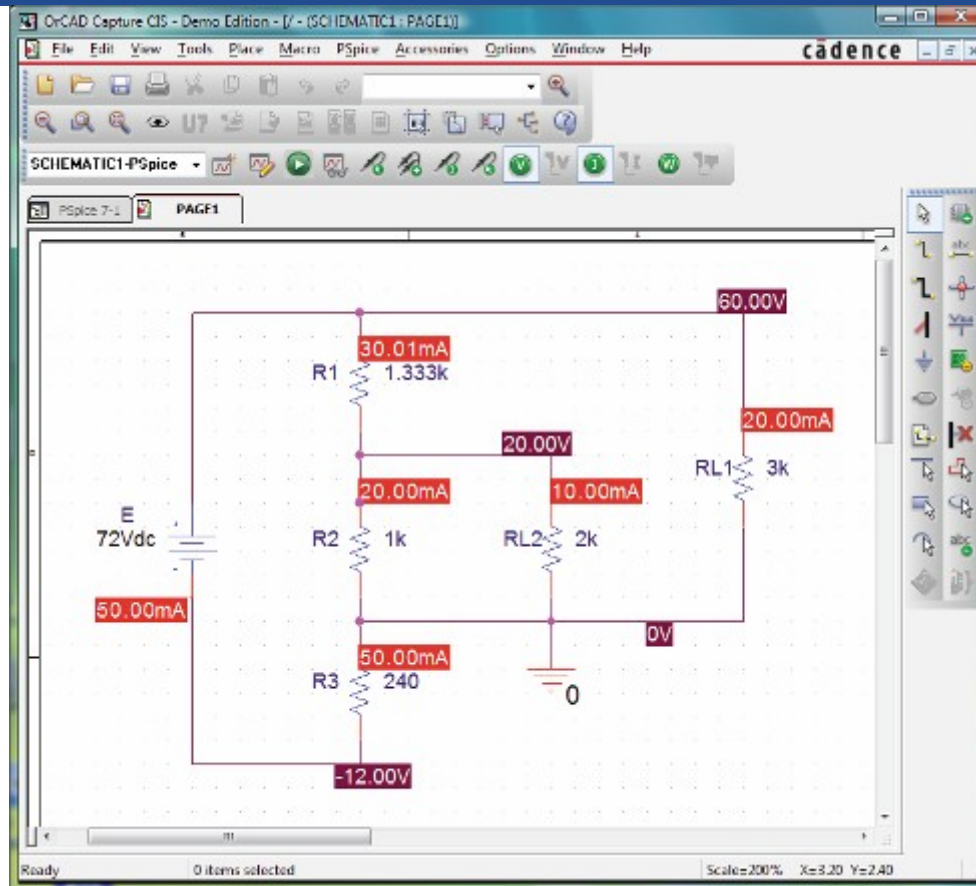
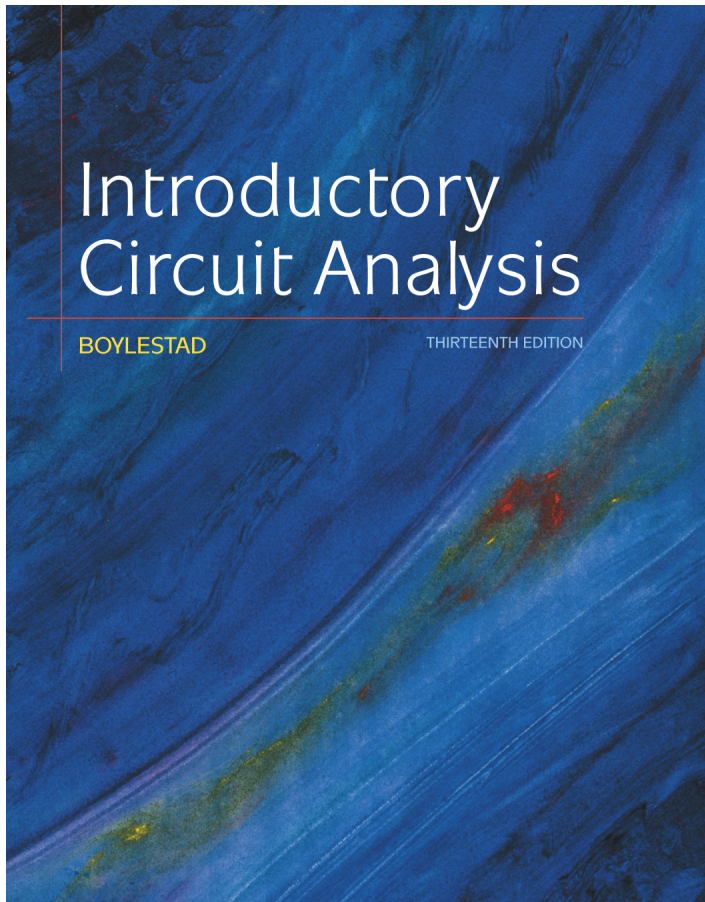


FIG. 7.63 *Using PSpice to verify the results of Example 7.12.*

Introductory Circuit Analysis



CHAPTER 9

Network Theorems

OBJECTIVES

- Become familiar with the superposition theorem and its unique ability to separate the impact of each source on the quantity of interest.
- Be able to apply Thévenin's theorem to reduce any two-terminal, series-parallel network with any number of sources to a single voltage source and series resistor.

OBJECTIVES

- Become familiar with Norton's theorem and how it can be used to reduce any two-terminal, seriesparallel network with any number of sources to a single current source and a parallel resistor.
- Understand how to apply the maximum power transfer theorem to determine the maximum power to a load and to choose a load that will receive maximum power.

OBJECTIVES

- Become aware of the reduction powers of Millman's theorem and the powerful implications of the substitution and reciprocity theorems.

INTRODUCTION

- This chapter introduces a number of theorems that have application throughout the field of electricity and electronics.
 - Not only can they be used to solve networks such as encountered in the previous chapter, but they also provide an opportunity to determine the impact of a particular source or element on the response of the entire system.

INTRODUCTION

- In most cases, the network to be analyzed and the mathematics required to find the solution are simplified

SUPERPOSITION THEOREM

- The superposition theorem is unquestionably one of the most powerful in this field.
- It has such widespread application that people often apply it without recognizing that their maneuvers are valid only because of this theorem.
- In general, the theorem can be used to do the following:

SUPERPOSITION THEOREM

- Analyze networks such as introduced in the last chapter that have two or more sources that are not in series or parallel.
- Reveal the effect of each source on a particular quantity of interest.
- For sources of different types (dc and ac, which affect the parameters of the network in a different manner) and apply a separate analysis for each type, with the total result simply the algebraic sum of the results.

SUPERPOSITION THEOREM

- The superposition theorem states the following:
 - The current through, or voltage across, any element of a network is equal to the algebraic sum of the currents or voltages produced independently by each source.

SUPERPOSITION THEOREM

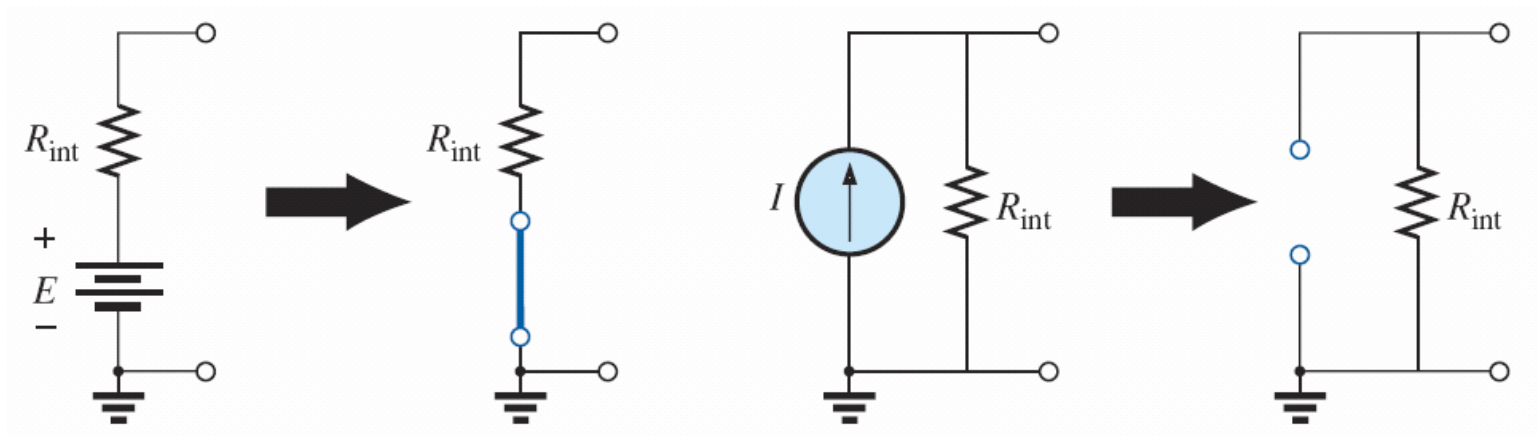


FIG. 9.1 *Removing a voltage source and a current source to permit the application of the superposition theorem.*

SUPERPOSITION THEOREM

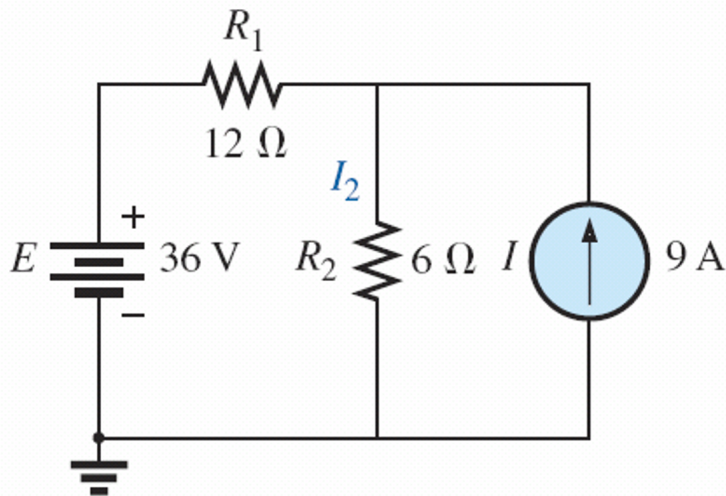


FIG. 9.2 Network to be analyzed in Example 9.1 using the superposition theorem.

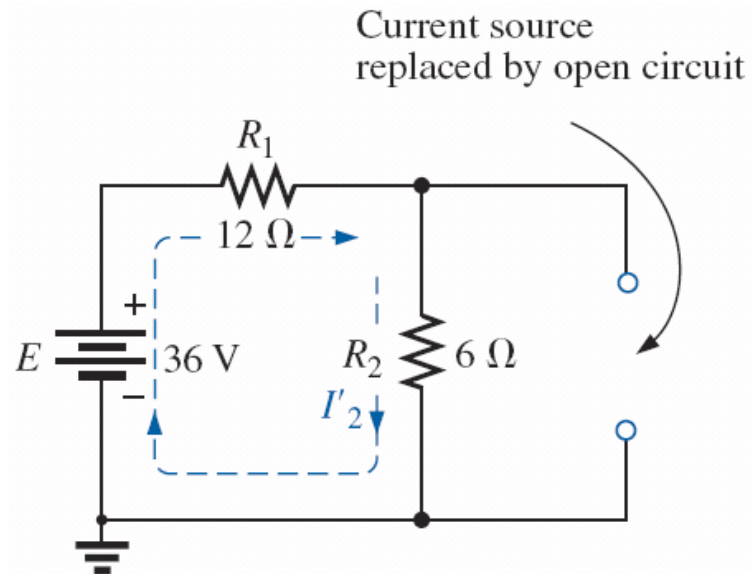


FIG. 9.3 Replacing the 9 A current source in Fig. 9.2 by an open circuit to determine the effect of the 36 V voltage source on current I_2 .

SUPERPOSITION THEOREM

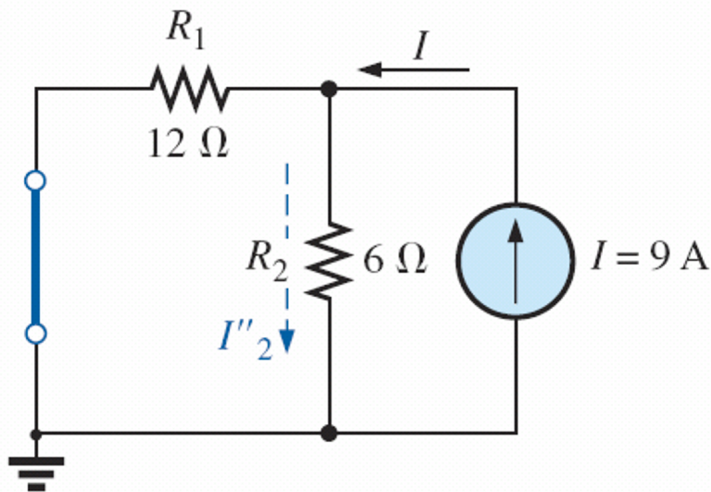


FIG. 9.4 Replacing the 36 V voltage source by a short-circuit equivalent to determine the effect of the 9 A current source on current I_2 .

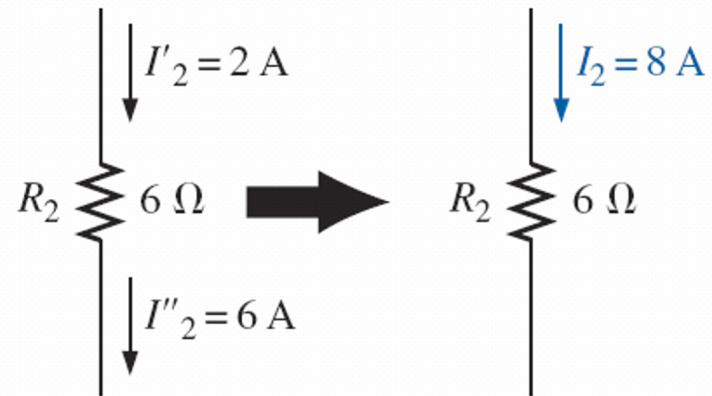


FIG. 9.5 Using the results of Figs. 9.3 and 9.4 to determine current I_2 for the network in Fig. 9.2.

SUPERPOSITION THEOREM

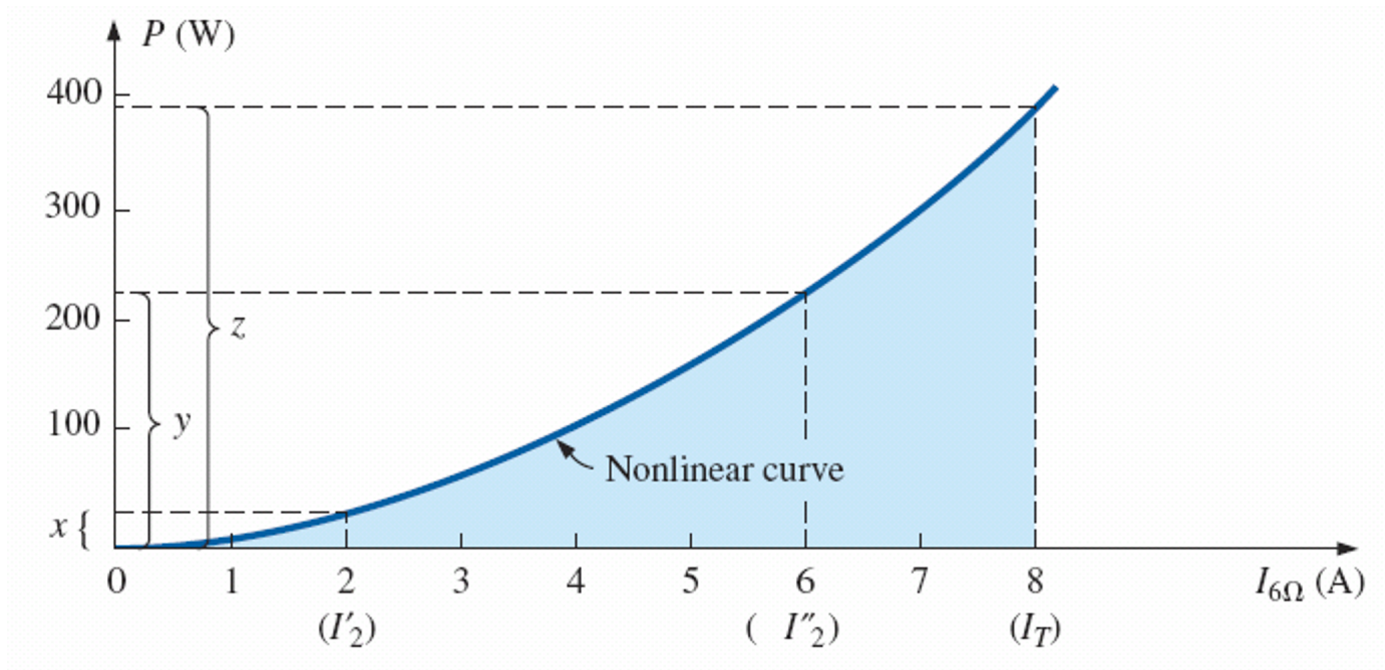


FIG. 9.6 *Plotting power delivered to the 6Ω resistor versus current through the resistor.*

SUPERPOSITION THEOREM

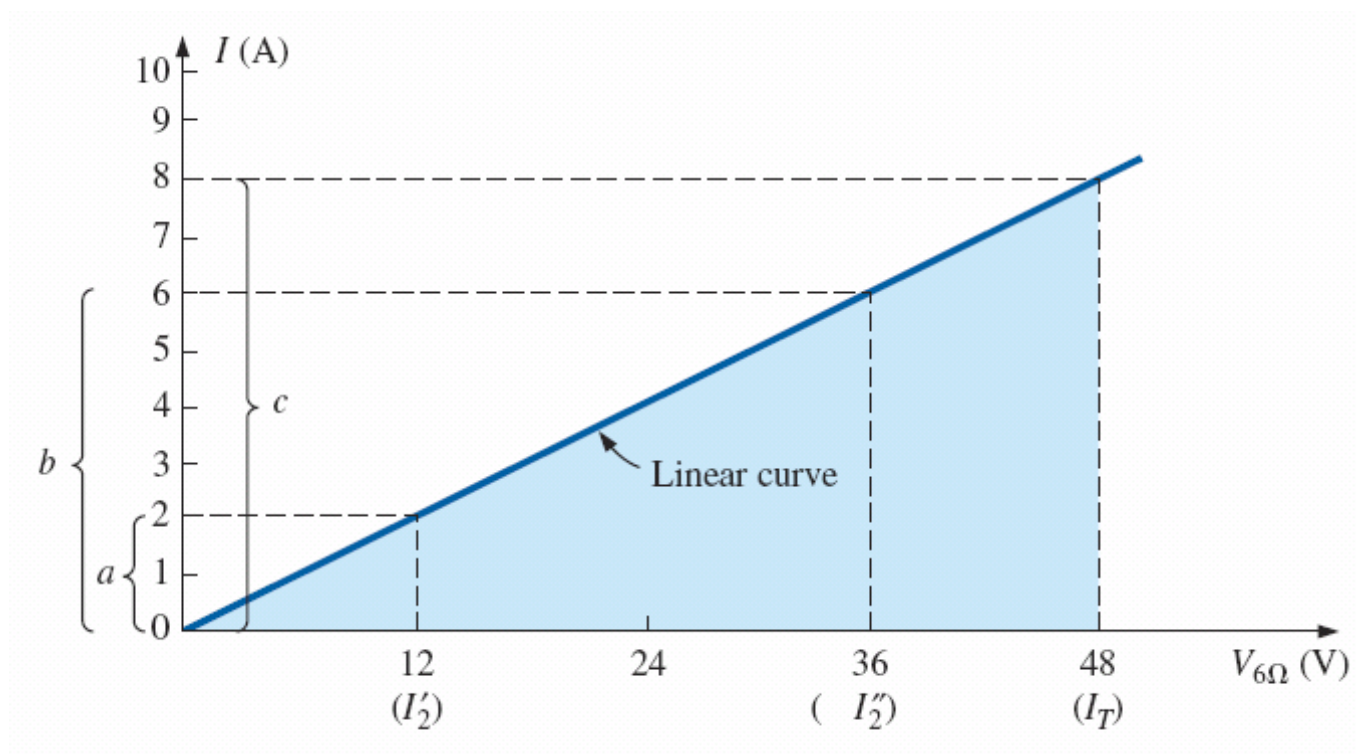


FIG. 9.7 *Plotting I versus V for the 6Ω resistor.*

SUPERPOSITION THEOREM

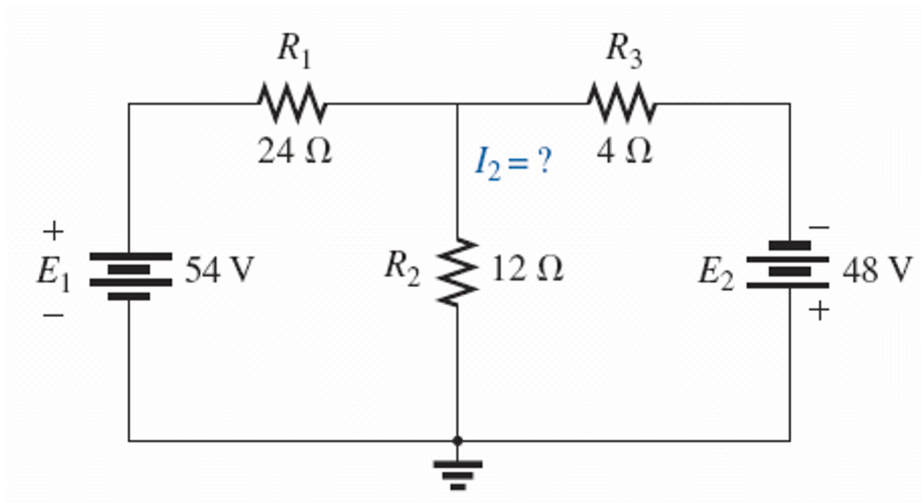


FIG. 9.8 *Using the superposition theorem to determine the current through the $12\ \Omega$ resistor (Example 9.2).*

SUPERPOSITION THEOREM

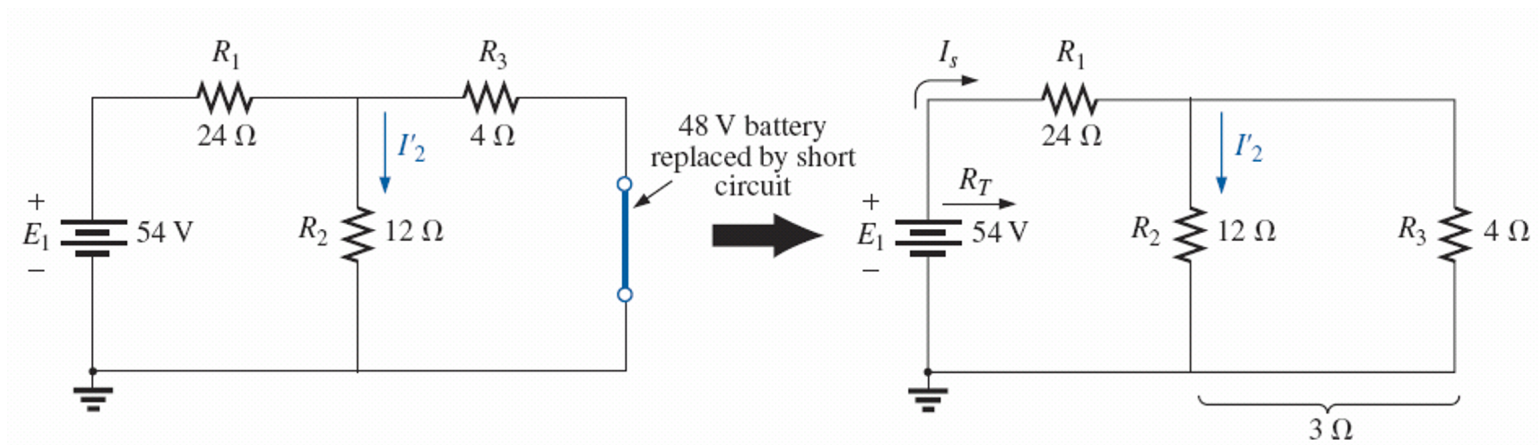


FIG. 9.9 Using the superposition theorem to determine the effect of the 54 V voltage source on current I_2 in Fig. 9.8.

SUPERPOSITION THEOREM

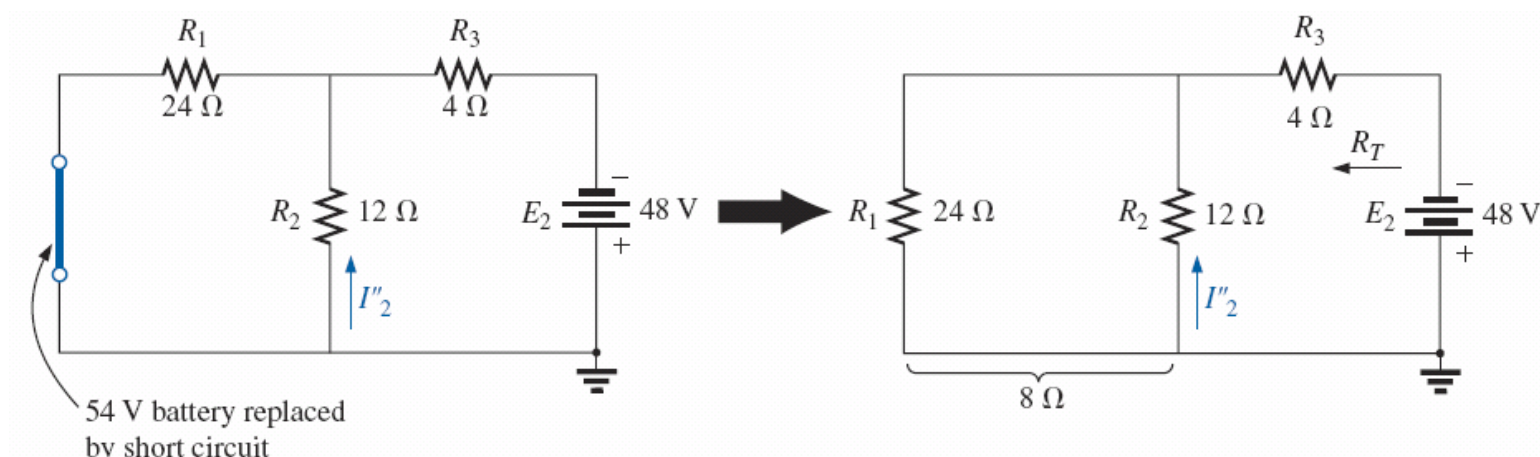


FIG. 9.10 Using the superposition theorem to determine the effect of the 48 V voltage source on current I_2 in Fig. 9.8.

SUPERPOSITION THEOREM

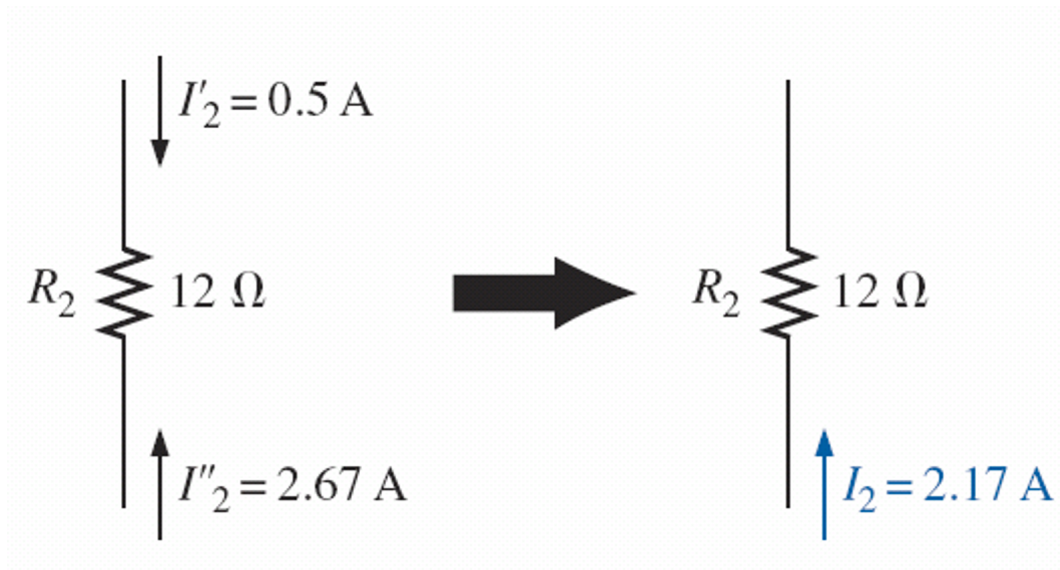


FIG. 9.11 *Using the results of Figs. 9.9 and 9.10 to determine current I_2 for the network in Fig. 9.8.*

SUPERPOSITION THEOREM

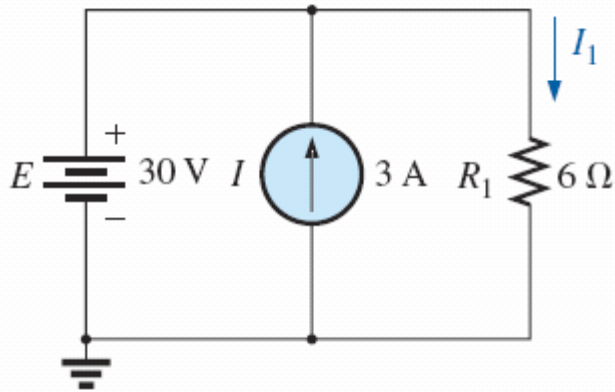


FIG. 9.12 *Two-source network to be analyzed using the superposition theorem in Example 9.3.*

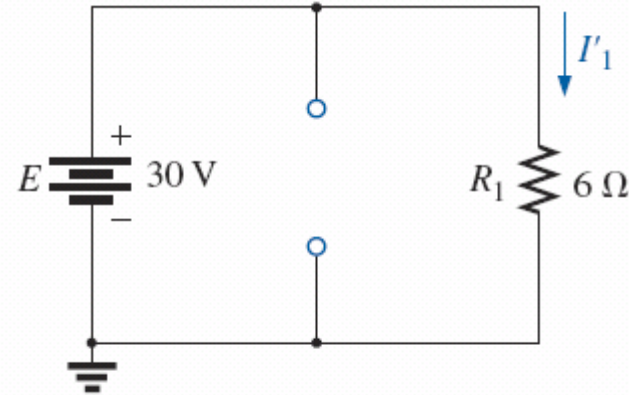


FIG. 9.13 *Determining the effect of the 30 V supply on the current I_1 in Fig. 9.12.*

SUPERPOSITION THEOREM

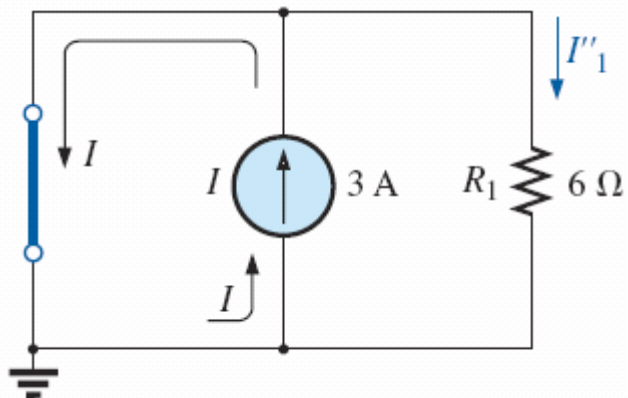


FIG. 9.14

Determining the effect of the 3 A current source on the current I_1 in Fig. 9.12.

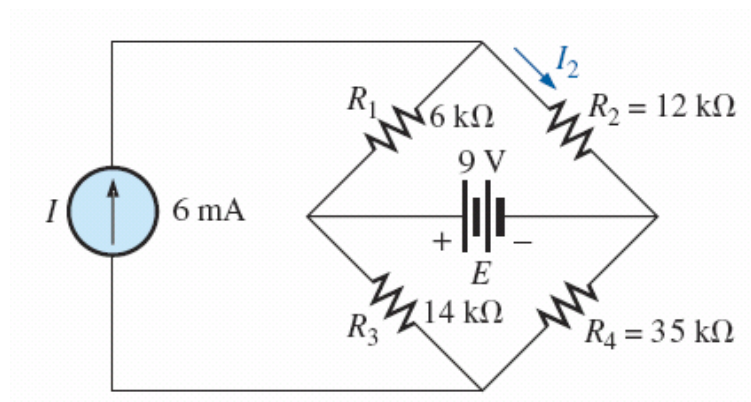


FIG. 9.15

Example 9.4.

SUPERPOSITION THEOREM

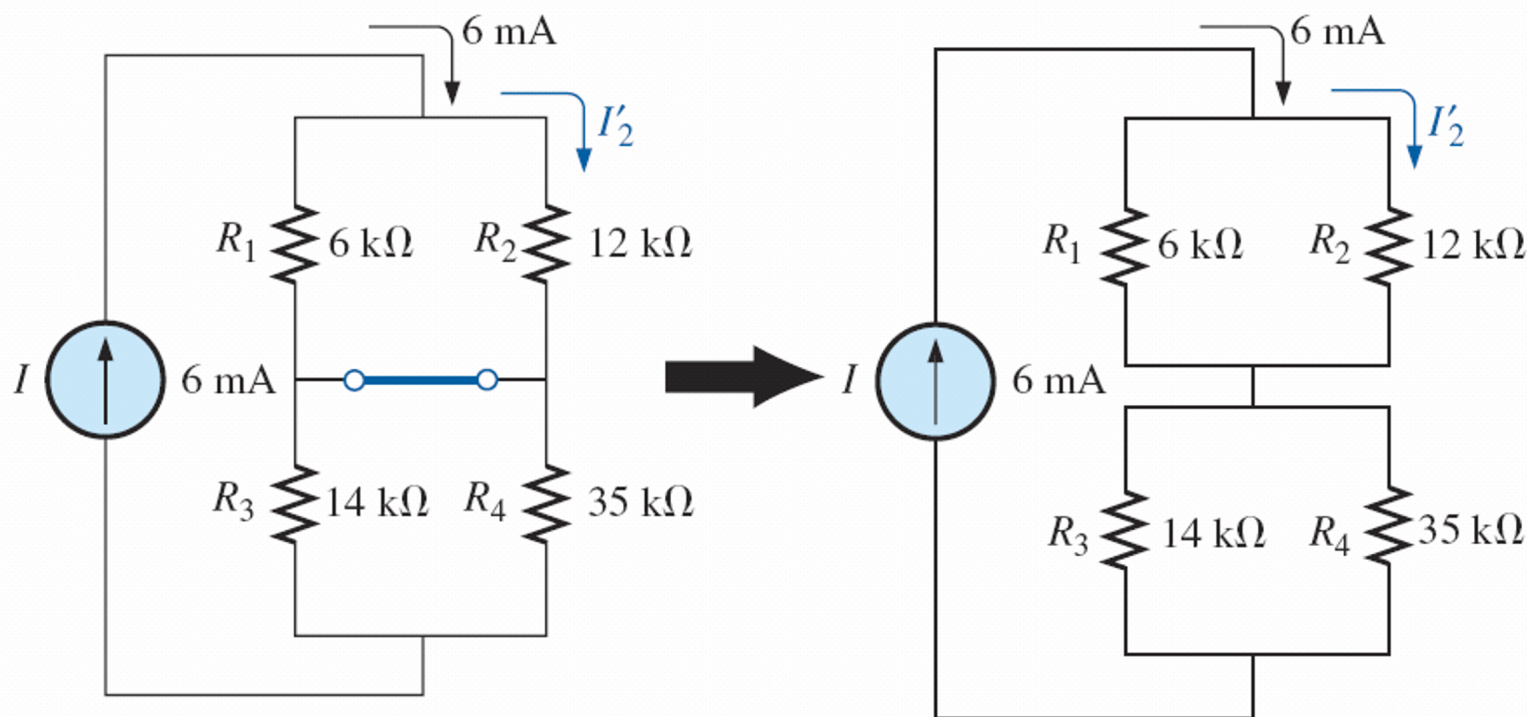


FIG. 9.16 *The effect of the current source I on the current I'_2 .*

SUPERPOSITION THEOREM

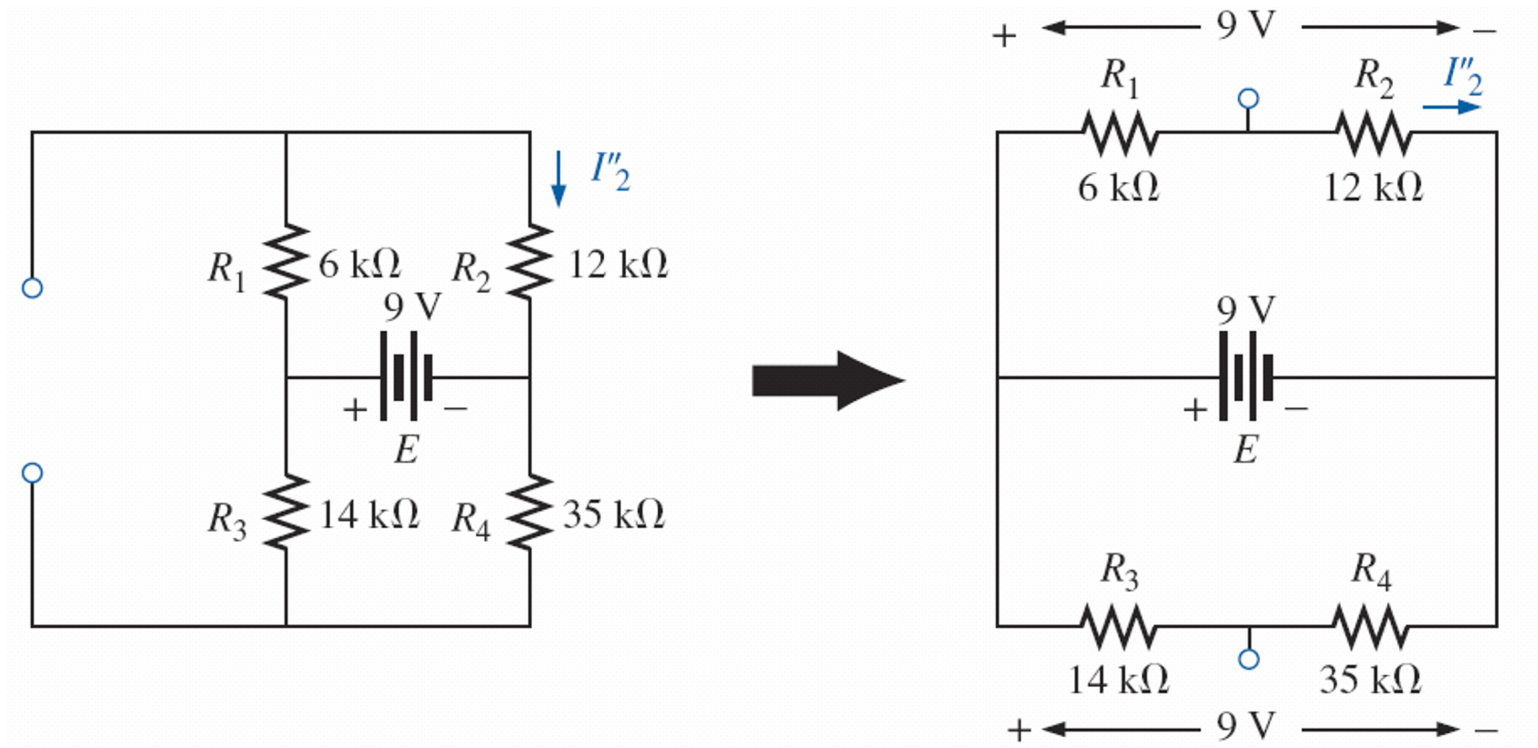


FIG. 9.17 *The effect of the voltage source E on the current I_2 .*

SUPERPOSITION THEOREM

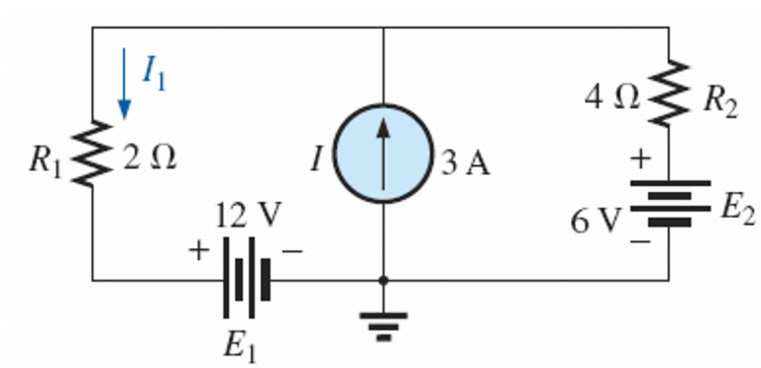


FIG. 9.18
Example 9.5.

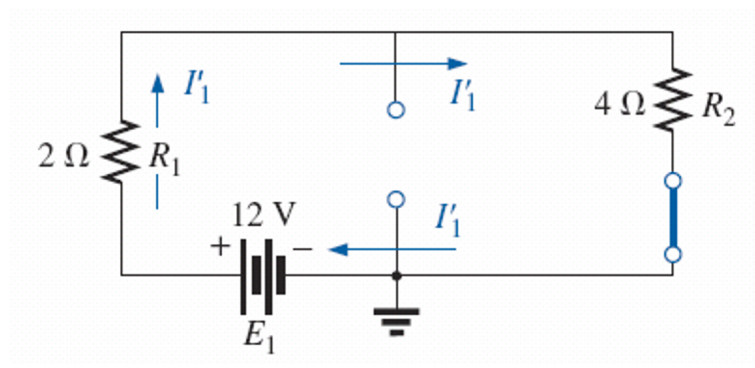


FIG. 9.19 *The effect of E_1 on the current I .*

SUPERPOSITION THEOREM

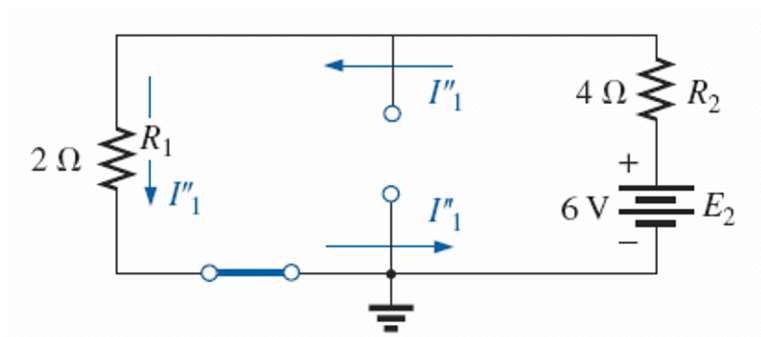


FIG. 9.20 *The effect of E_2 on the current I_1 .*

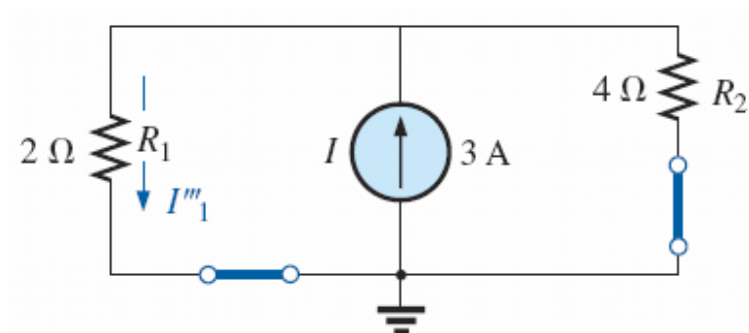


FIG. 9.21 *The effect of I on the current I_1 .*

SUPERPOSITION THEOREM

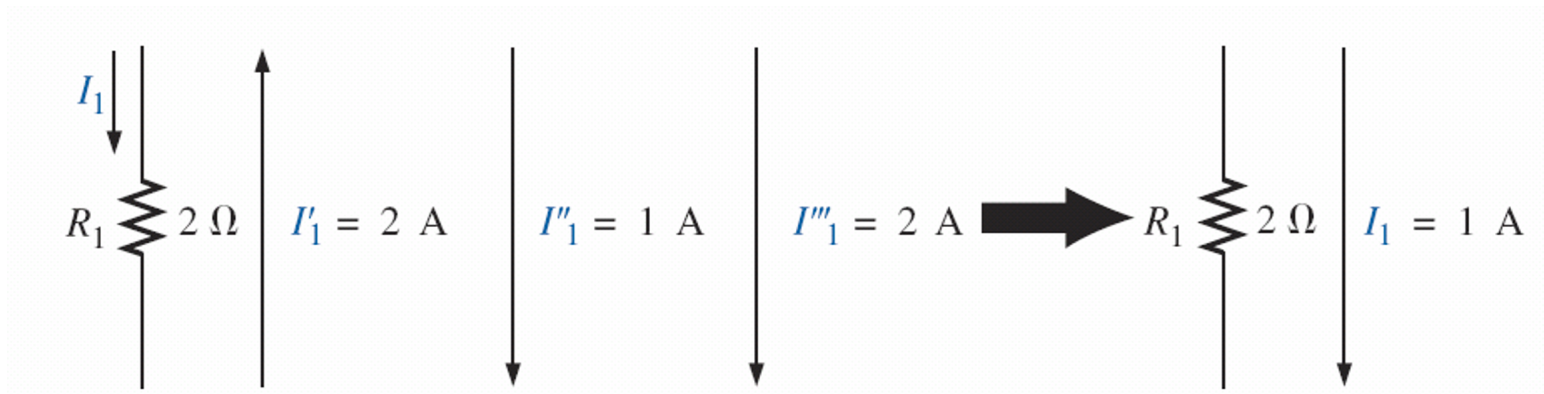


FIG. 9.22 *The resultant current I_1 .*

THÉVENIN'S THEOREM

- The next theorem to be introduced, Thévenin's theorem, is probably one of the most interesting in that it permits the reduction of complex networks to a simpler form for analysis and design.
- In general, the theorem can be used to do the following:

THÉVENIN'S THEOREM

- Analyze networks with sources that are not in series or parallel.
- Reduce the number of components required to establish the same characteristics at the output terminals.
- Investigate the effect of changing a particular component on the behavior of a network without having to analyze the entire network after each change.

THÉVENIN'S THEOREM

- Thévenin's theorem states the following:
 - Any two-terminal dc network can be replaced by an equivalent circuit consisting solely of a voltage source and a series resistor.

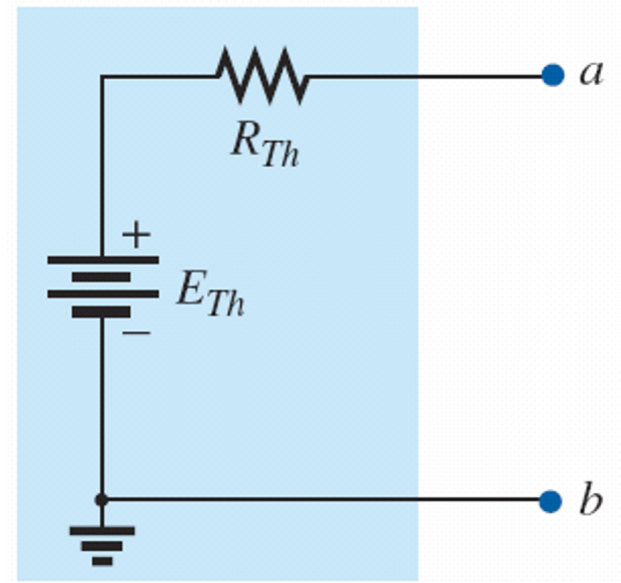


FIG. 9.23 *Thévenin equivalent circuit.*

THÉVENIN'S THEOREM

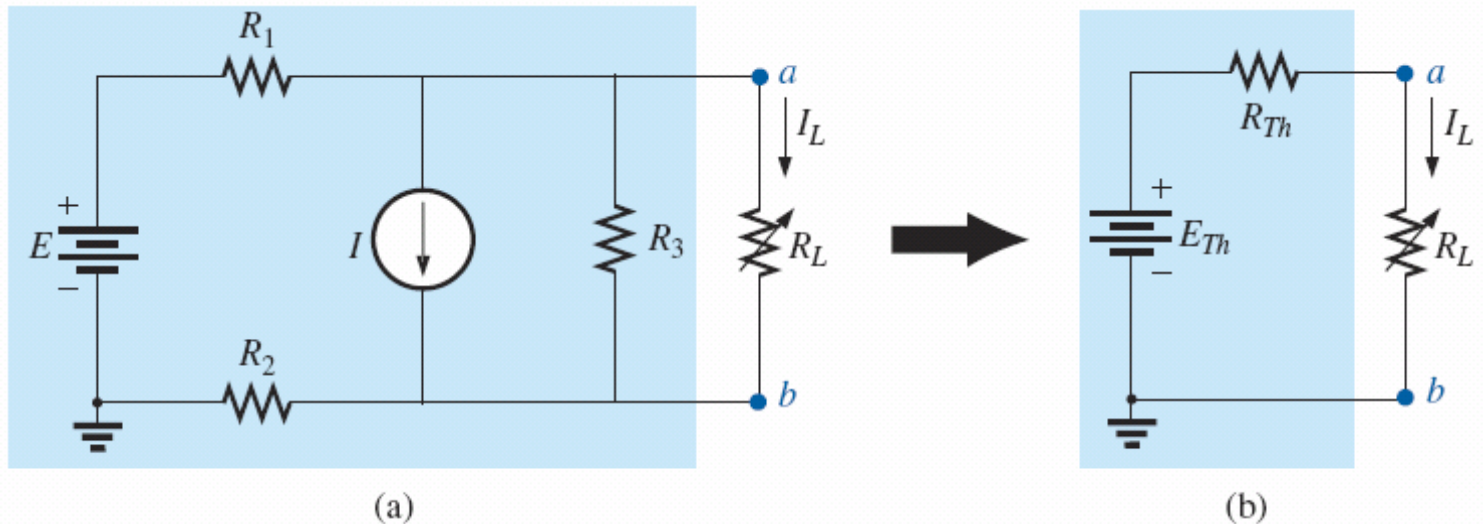


FIG. 9.25 *Substituting the Thévenin equivalent circuit for a complex network.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- Preliminary:
 - Remove that portion of the network where the Thévenin equivalent circuit is found.
 - Mark the terminals of the remaining two-terminal network.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- RTh:
 - Calculate RTh by first setting all sources to zero (voltage sources are replaced by short circuits and current sources by open circuits) and then finding the resultant resistance between the two marked terminals. (If the internal resistance of the voltage and/or current sources is included in the original network, it must remain when the sources are set to zero.)

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- ETh:
 - Calculate ETh by first returning all sources to their original position and finding the open-circuit voltage between the marked terminals. (This step is invariably the one that causes most confusion and errors. In all cases, keep in mind that it is the opencircuit potential between the two terminals marked in step 2.)

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

- Conclusion:
 - Draw the Thévenin equivalent circuit with the portion of the circuit previously removed replaced between the terminals of the equivalent circuit. This step is indicated by the placement of the resistor R_L between the terminals of the Thévenin equivalent circuit.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

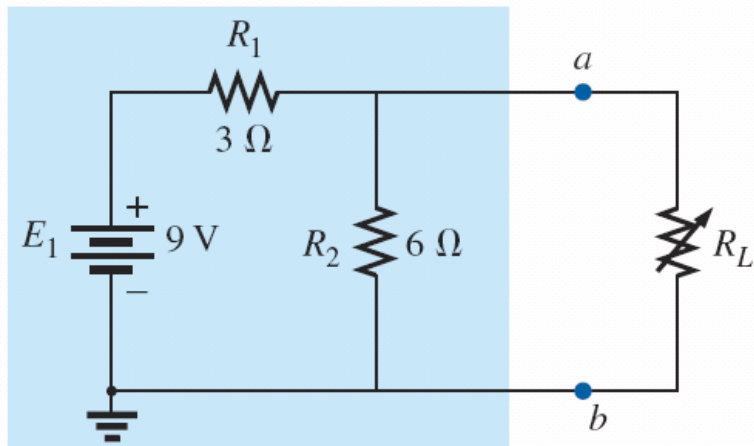


FIG. 9.26
Example 9.6.

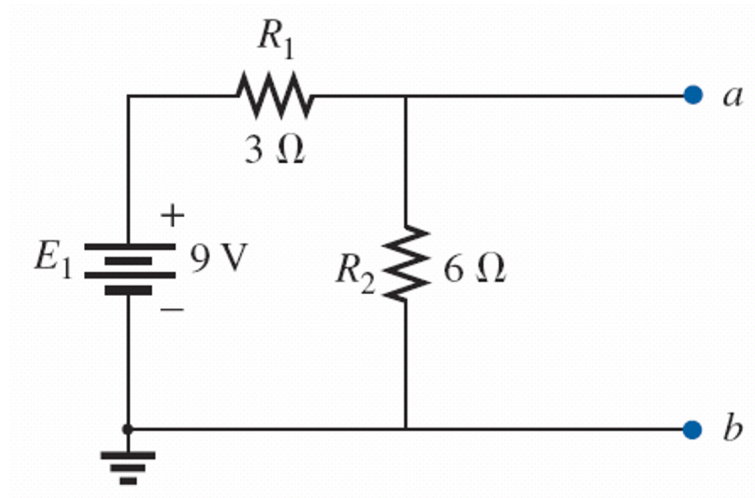


FIG. 9.27 *Identifying the terminals of particular importance when applying Thévenin's theorem.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

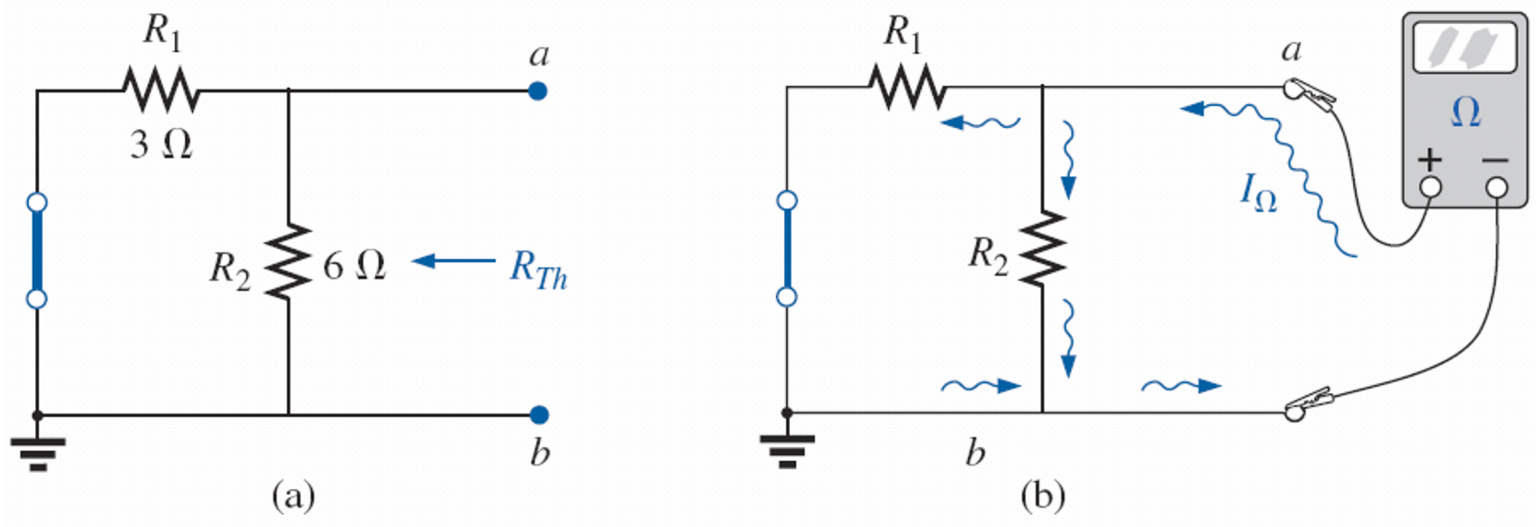


FIG. 9.28 *Determining R_{Th} for the network in Fig. 9.27.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

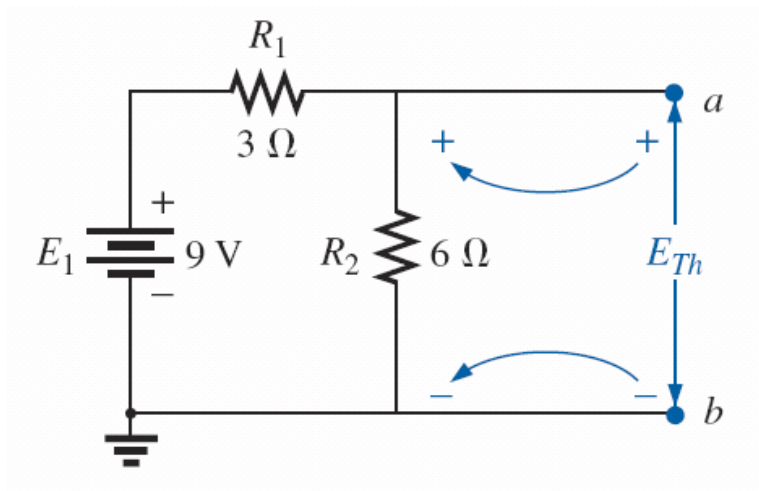


FIG. 9.29 *Determining E_{Th} for the network in Fig. 9.27.*

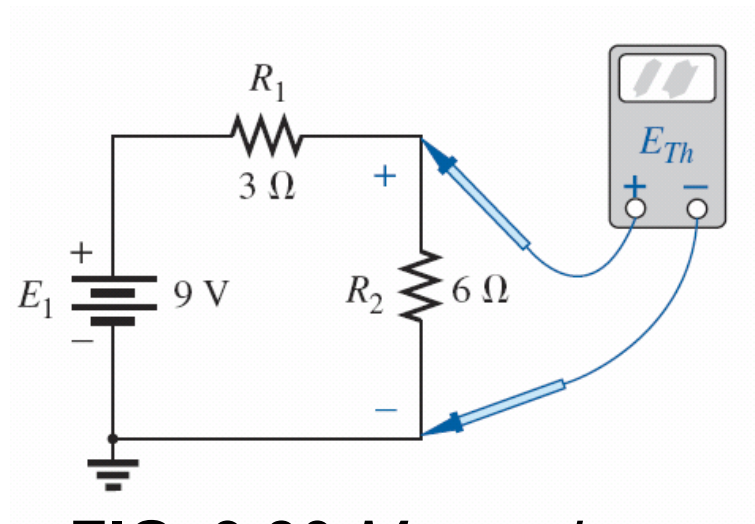


FIG. 9.30 *Measuring E_{Th} for the network in Fig. 9.27.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

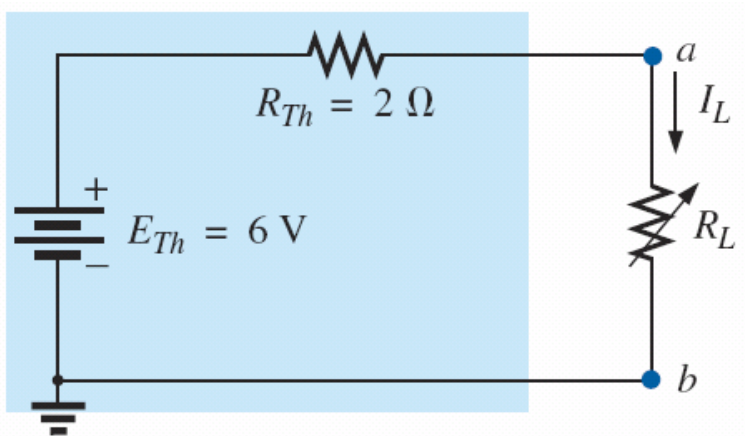


FIG. 9.31 *Substituting the Thévenin equivalent circuit for the network external to R_L in Fig. 9.26.*

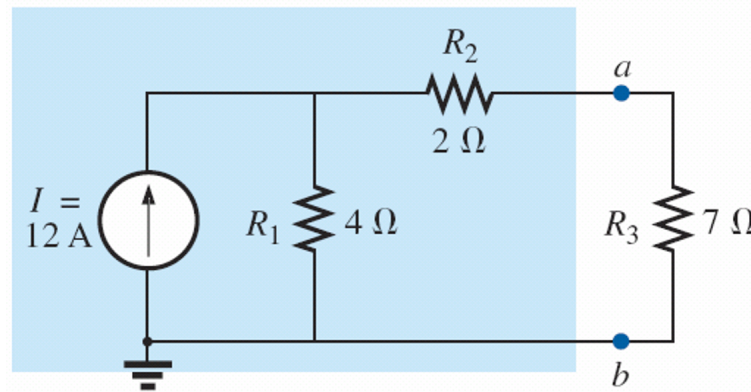


FIG. 9.32
Example 9.7.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

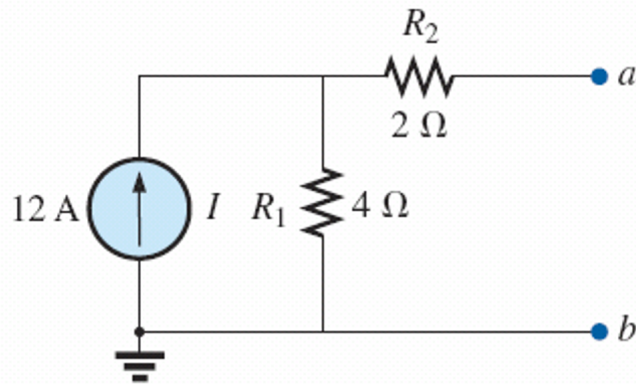


FIG. 9.33
Establishing the terminals of particular interest for the network in Fig. 9.32.

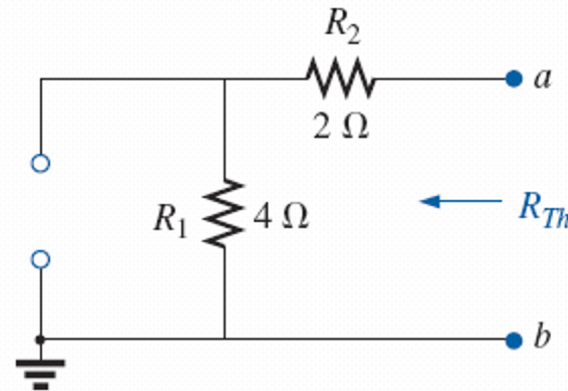


FIG. 9.34
Determining R_{Th} for the network in Fig. 9.33.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

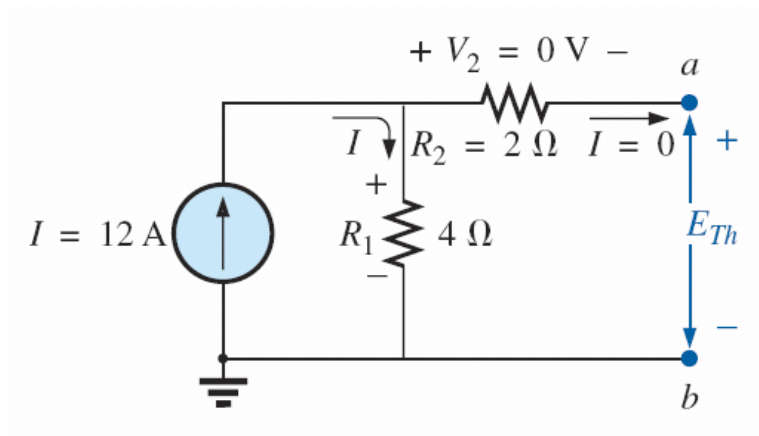


FIG. 9.35 Determining E_{Th} for the network in Fig. 9.33.

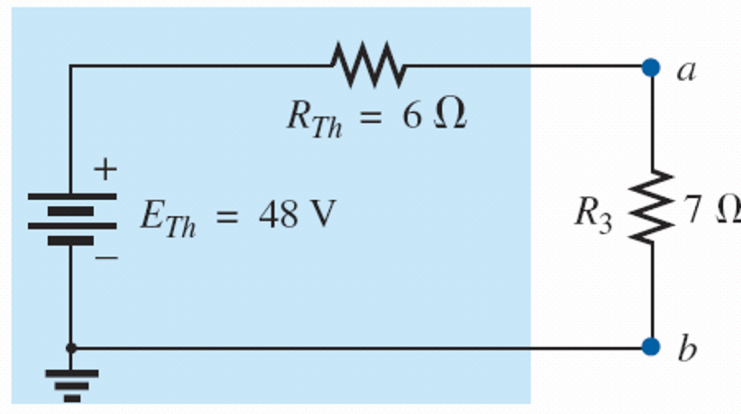


FIG. 9.36 Substituting the Thévenin equivalent circuit in the network external to the resistor R_3 in Fig. 9.32.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

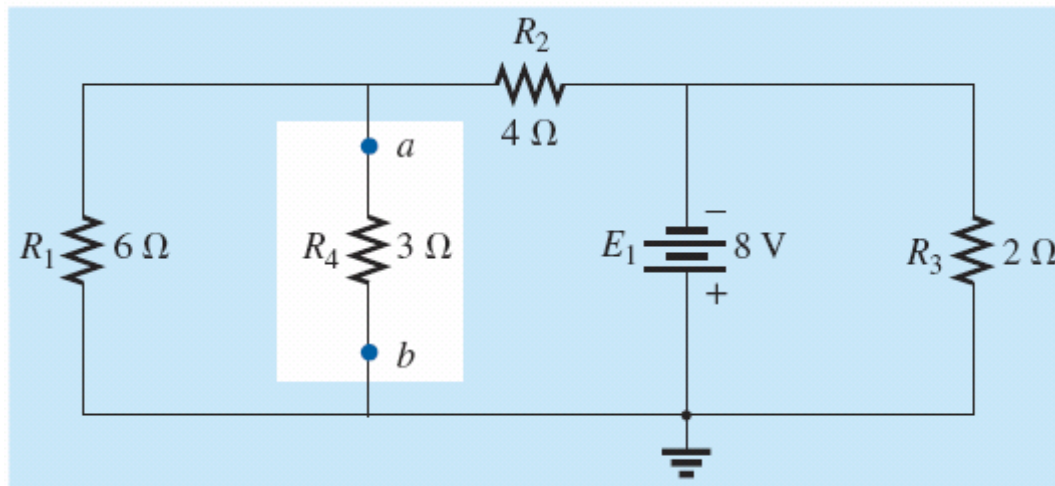


FIG. 9.37
Example 9.8.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

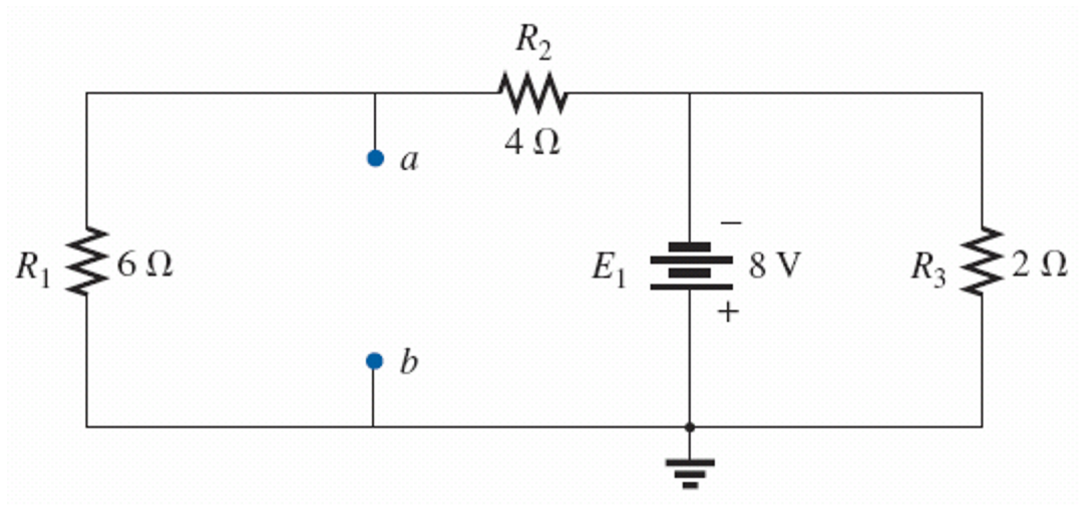


FIG. 9.38 *Identifying the terminals of particular interest for the network in Fig. 9.37.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

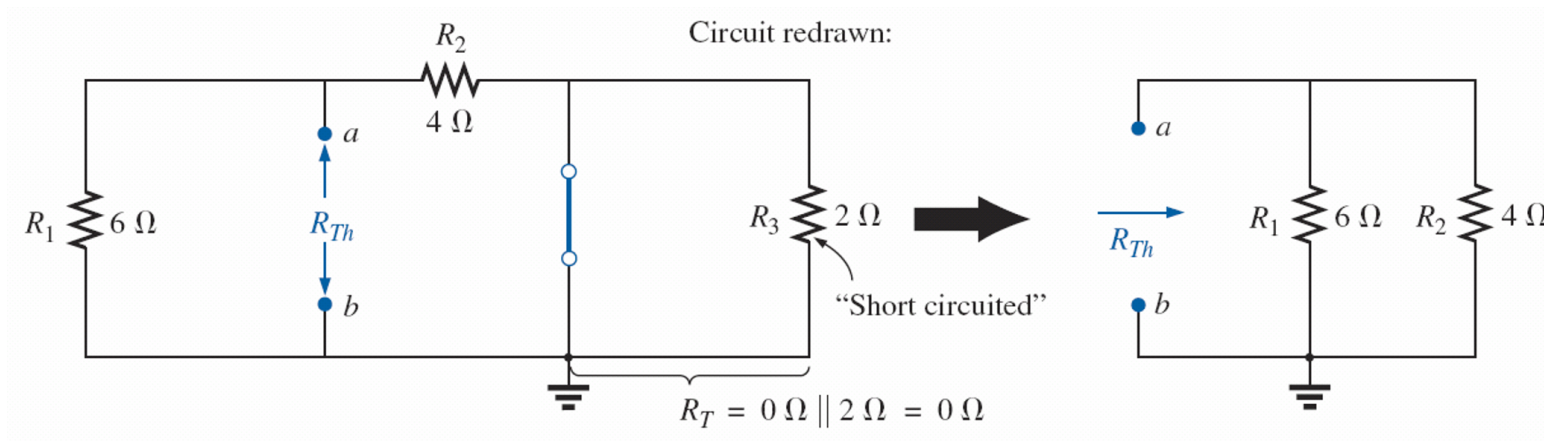


FIG. 9.39 Determining R_{Th} for the network in Fig. 9.38.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

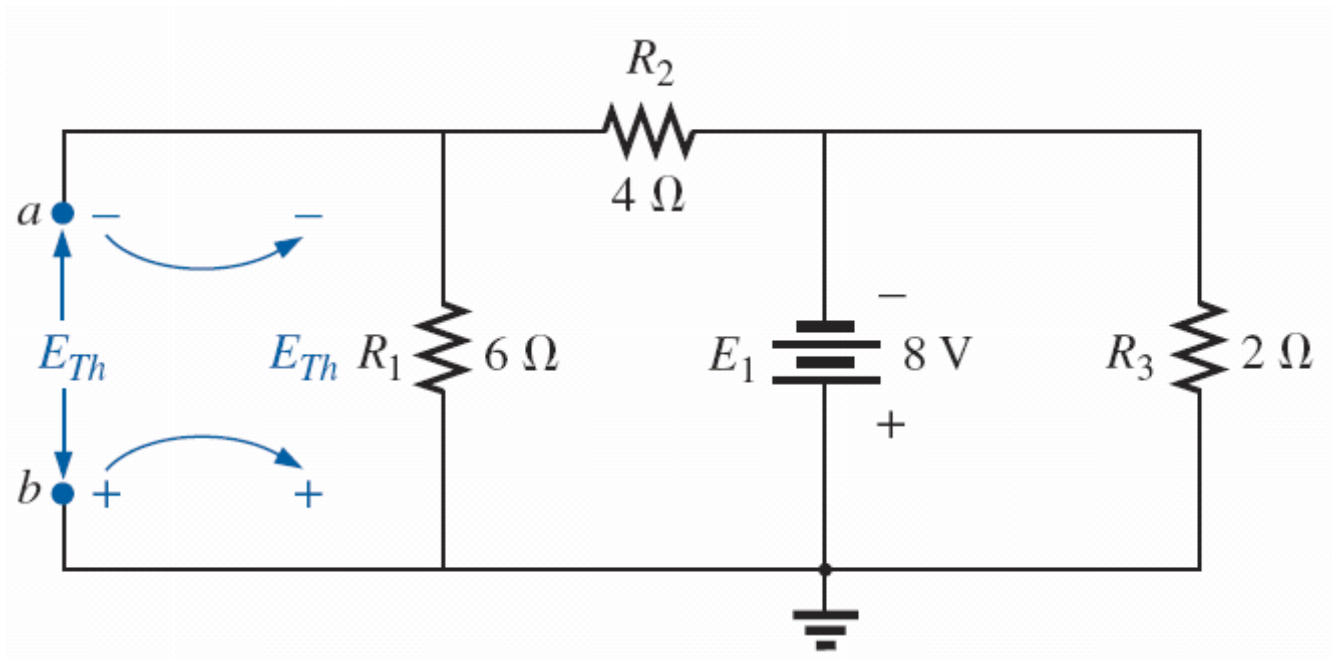


FIG. 9.40 *Determining E_{Th} for the network in Fig. 9.38.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

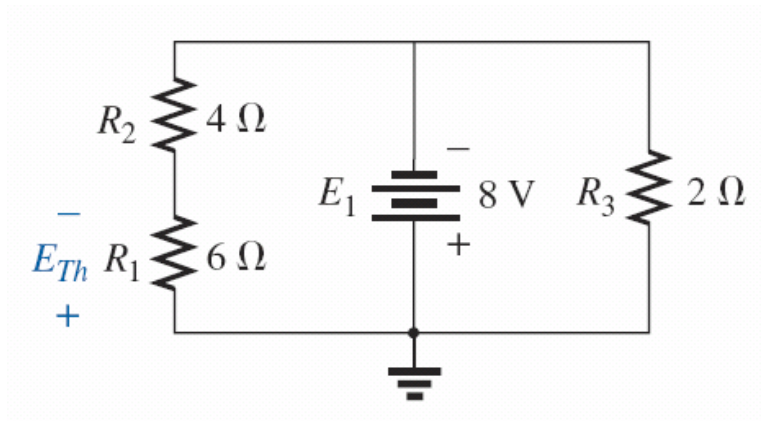


FIG. 9.41 Network of Fig. 9.40 redrawn.

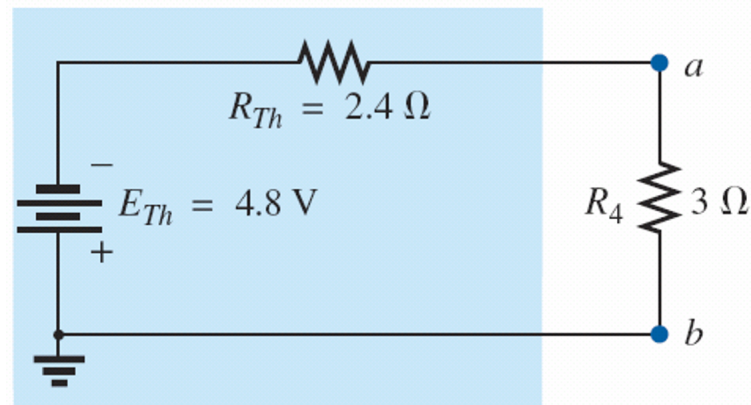


FIG. 9.42 Substituting the Thévenin equivalent circuit for the network external to the resistor R_4 in Fig. 9.37.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

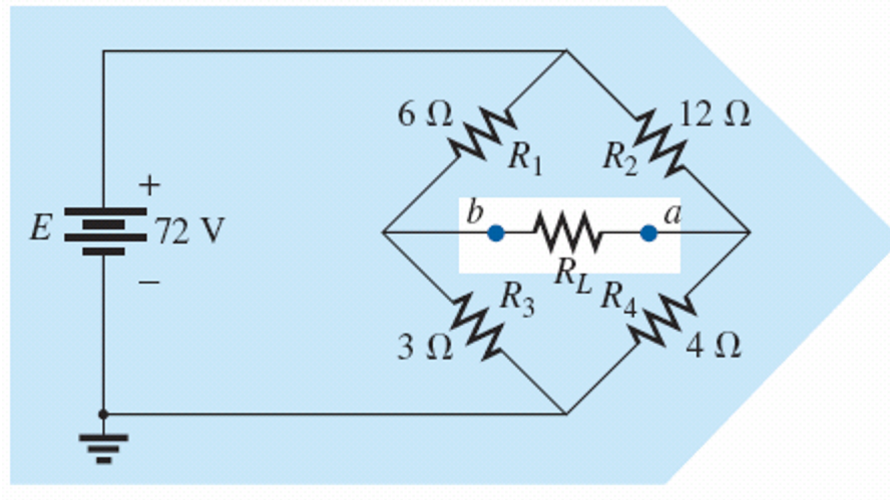


FIG. 9.43
Example 9.9.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

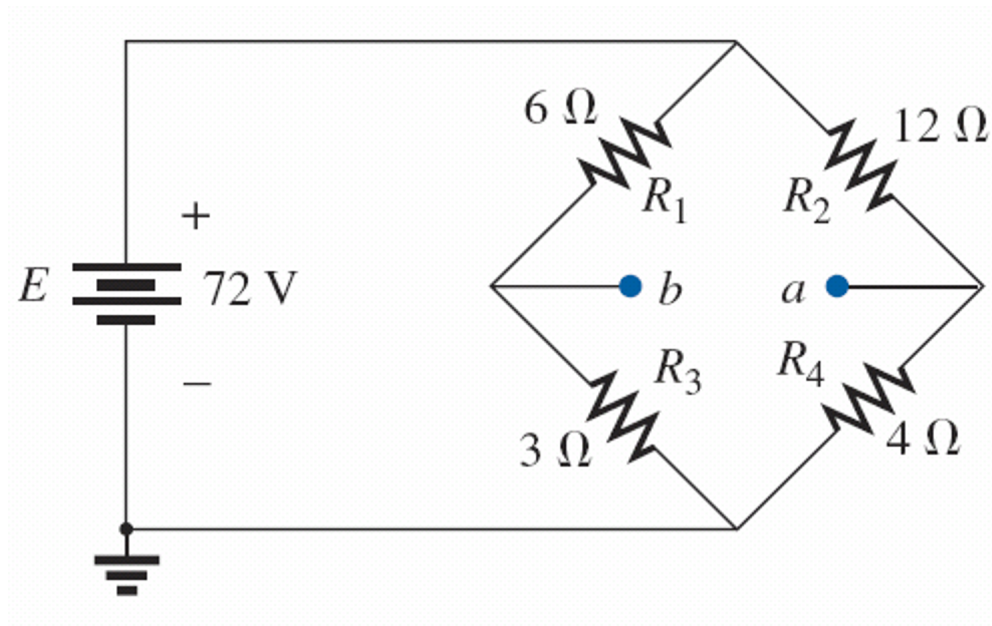


FIG. 9.44 *Identifying the terminals of particular interest for the network in Fig. 9.43.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

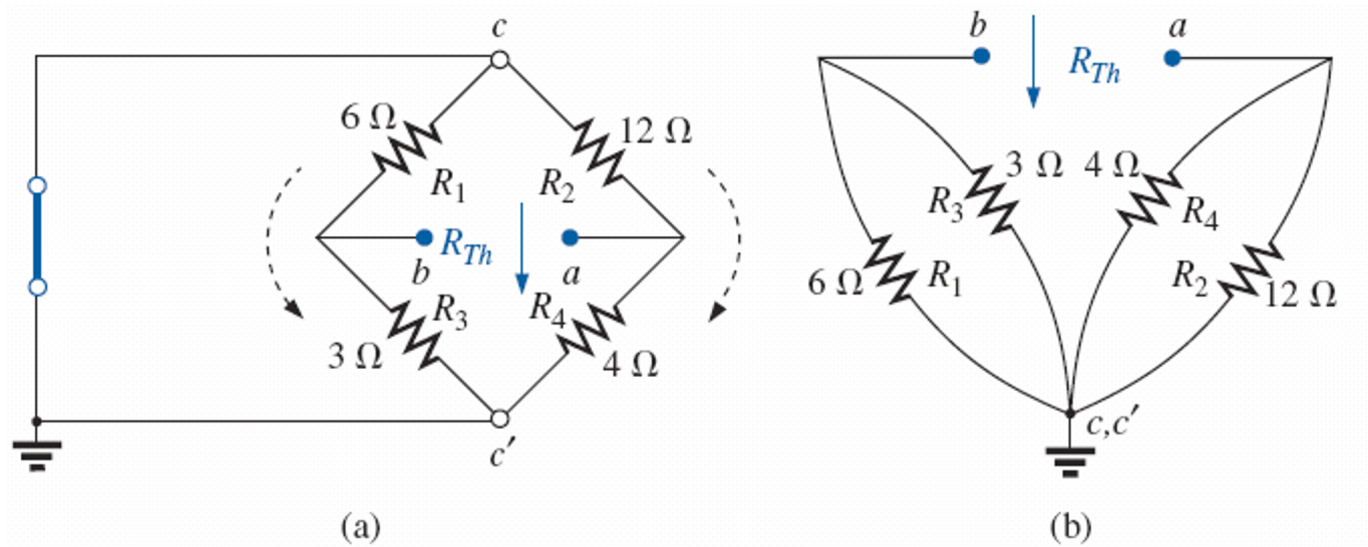


FIG. 9.45 Solving for R_{Th} for the network in Fig. 9.44.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

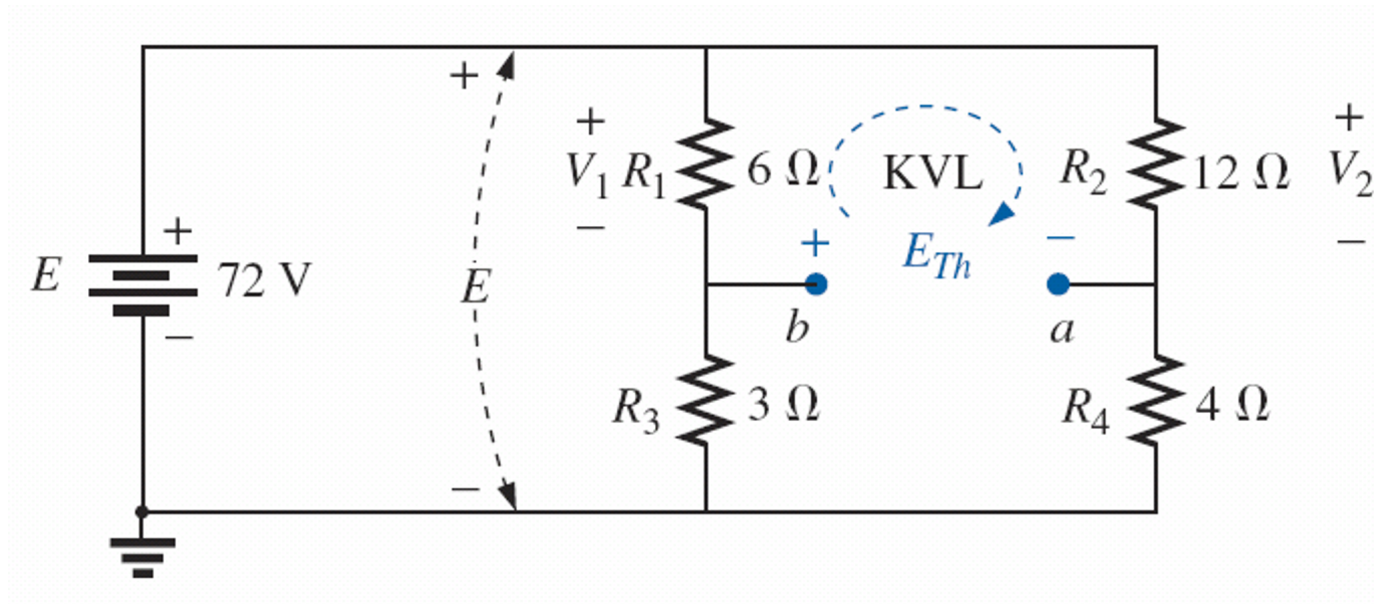


FIG. 9.46 Determining E_{Th} for the network in Fig. 9.44.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

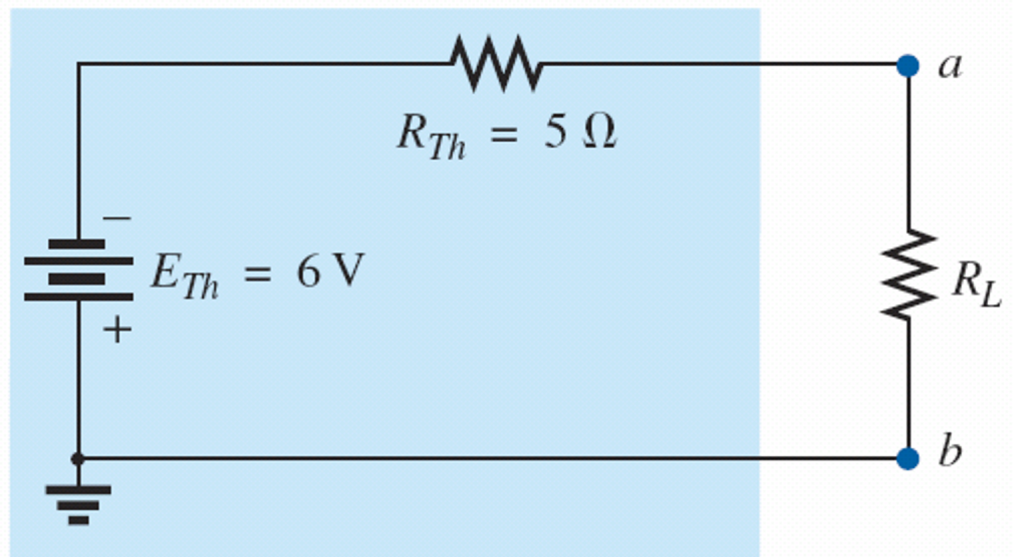


FIG. 9.47 *Substituting the Thévenin equivalent circuit for the network external to the resistor R_L in Fig. 9.43.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

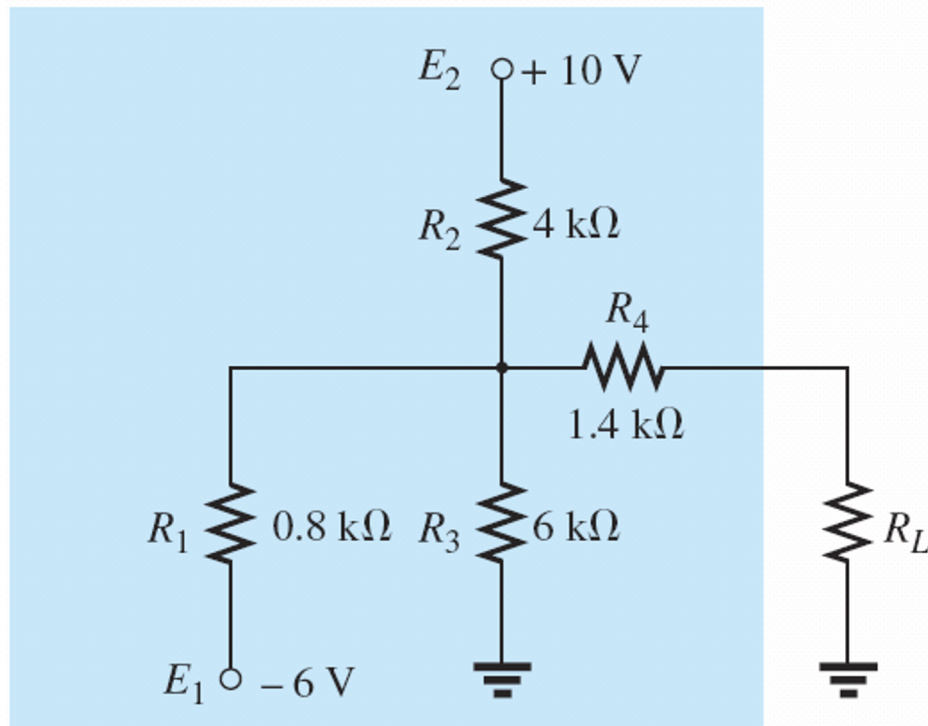


FIG. 9.48
Example 9.10.

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

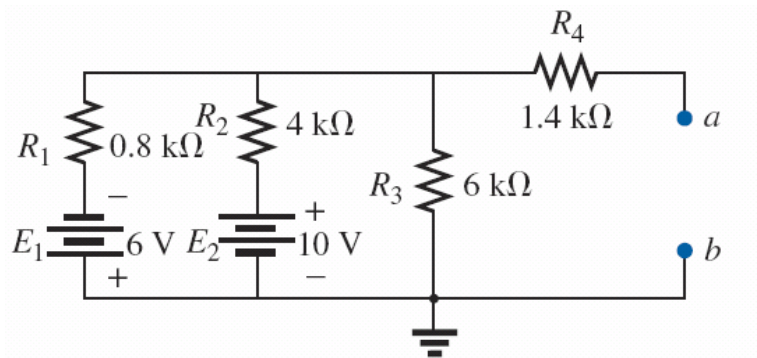


FIG. 9.49 *Identifying the terminals of particular interest for the network in Fig. 9.48.*

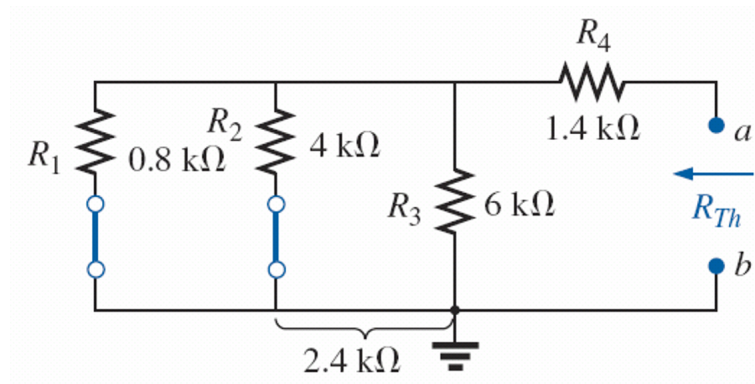


FIG. 9.50 *Determining R_{Th} for the network in Fig. 9.49.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

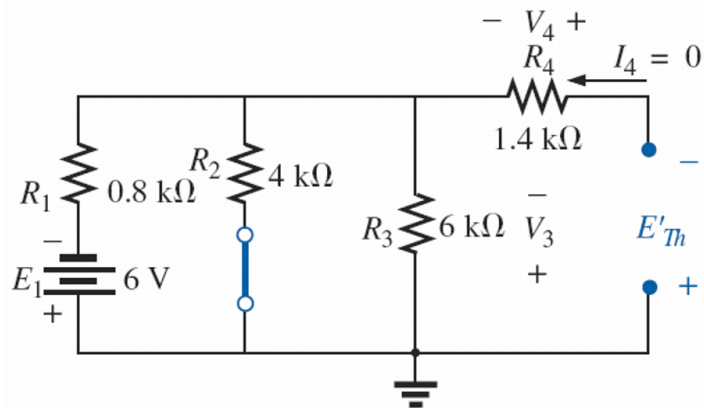


FIG. 9.51 *Determining the contribution to E_{Th} from the source E_1 for the network in Fig. 9.49.*

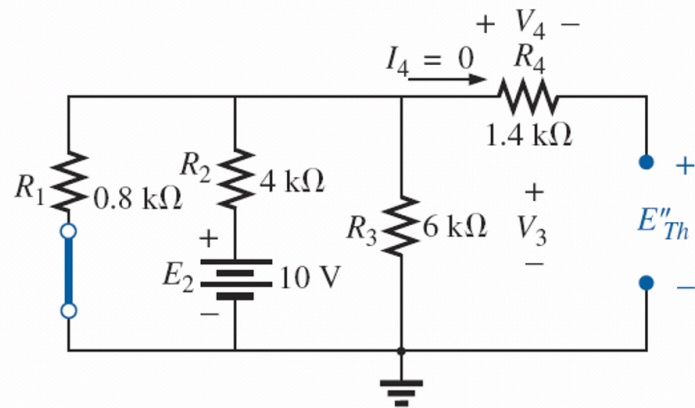


FIG. 9.52 *Determining the contribution to E_{Th} from the source E_2 for the network in Fig. 9.49.*

THÉVENIN'S THEOREM

Thévenin's Theorem Procedure

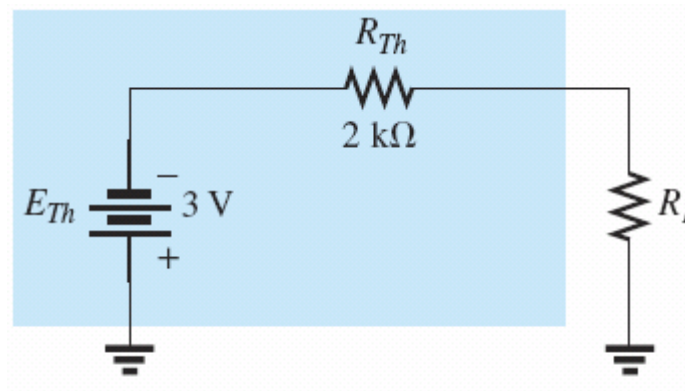


FIG. 9.53 *Substituting the Thévenin equivalent circuit for the network external to the resistor R_L in Fig. 9.48.*

THÉVENIN'S THEOREM

Experimental Procedures

- Measuring E_{th}
- Measuring R_{Th}

THÉVENIN'S THEOREM

Experimental Procedures

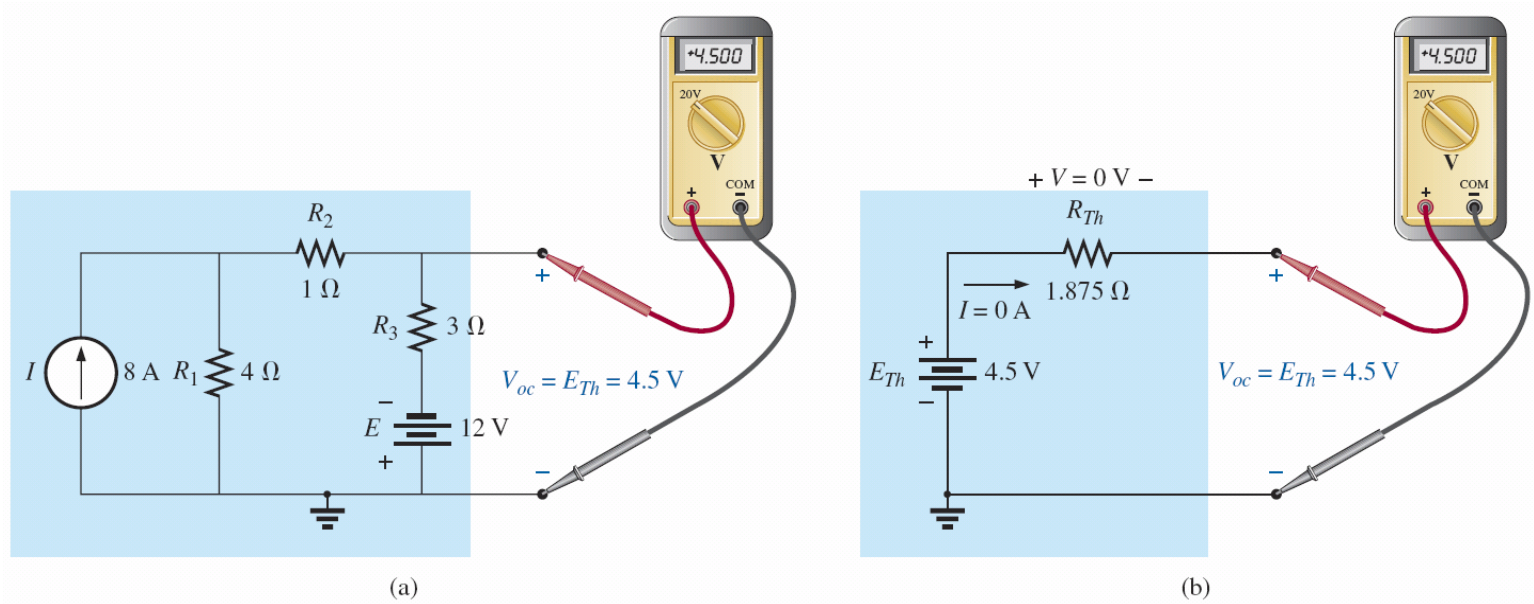


FIG. 9.60 *Measuring the Thévenin voltage with a voltmeter: (a) actual network; (b) Thévenin equivalent.*

THÉVENIN'S THEOREM

Experimental Procedures

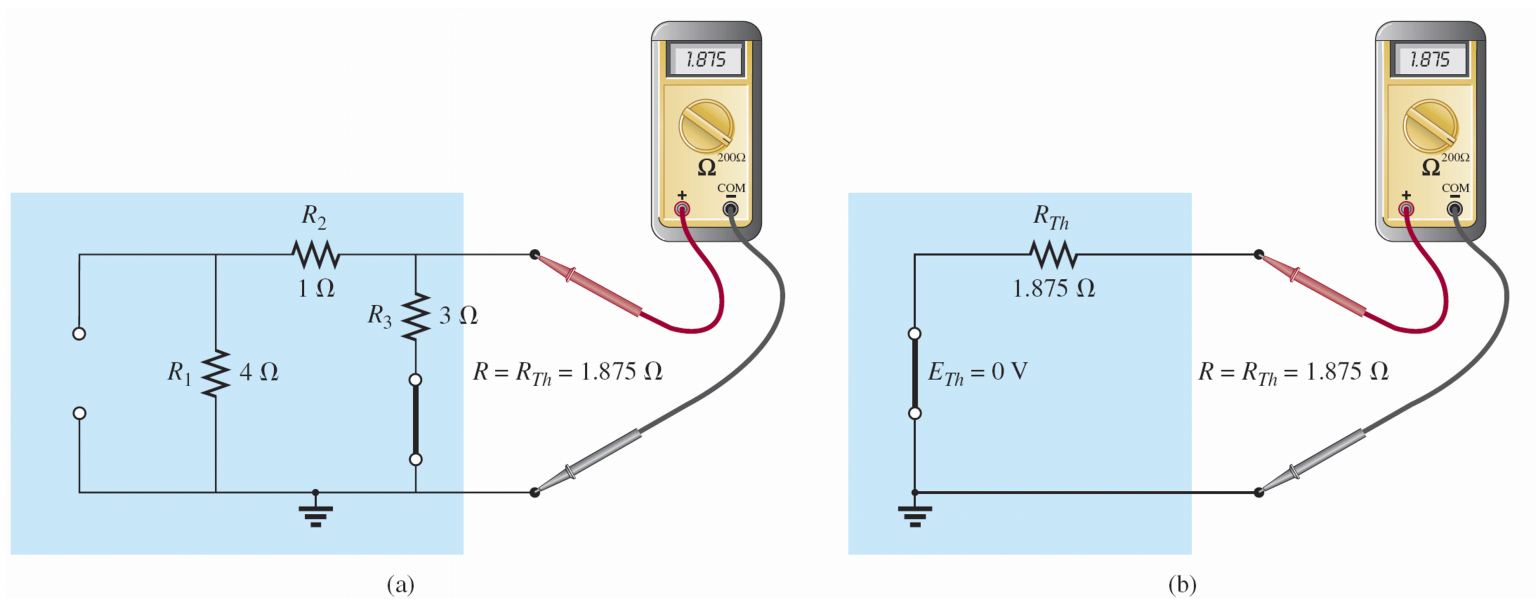


FIG. 9.61 *Measuring R_{Th} with an ohmmeter: (a) actual network; (b) Thévenin equivalent.*

THÉVENIN'S THEOREM

Experimental Procedures

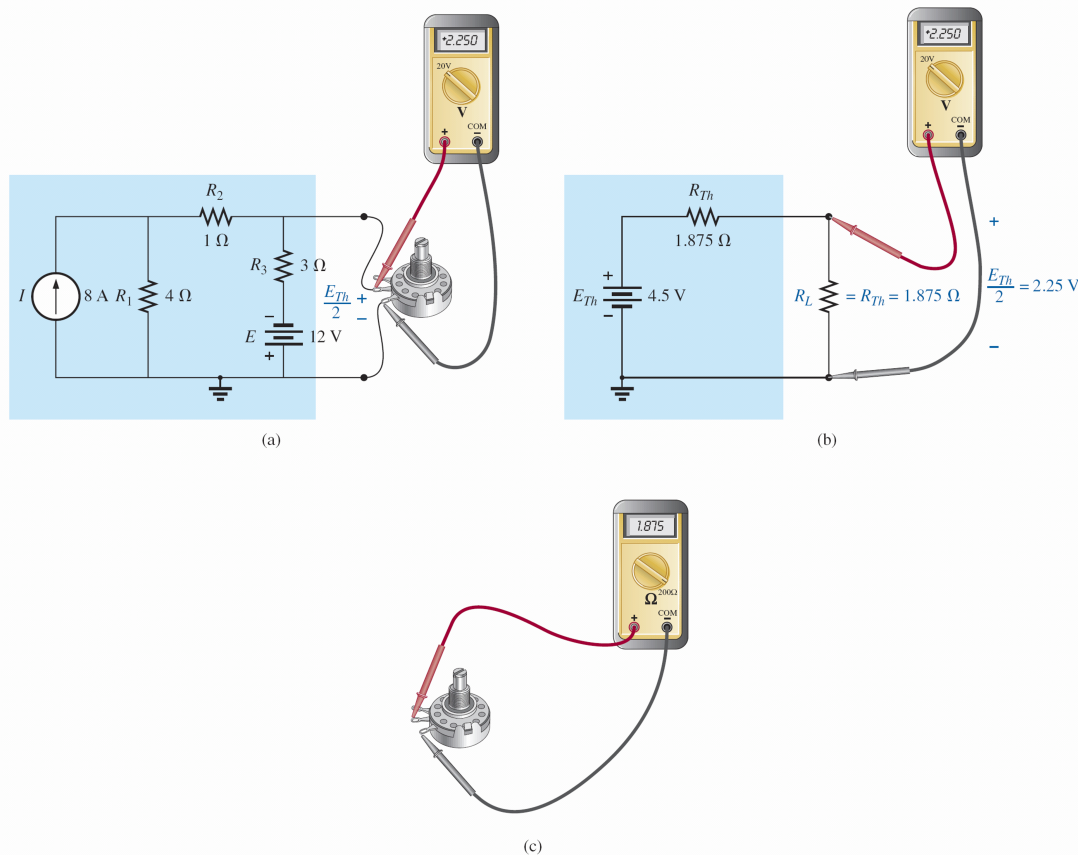


FIG. 9.62 Using a potentiometer to determine R_{Th} : (a) actual network; (b) Thévenin equivalent; (c) measuring R_{Th} .

THÉVENIN'S THEOREM

Experimental Procedures

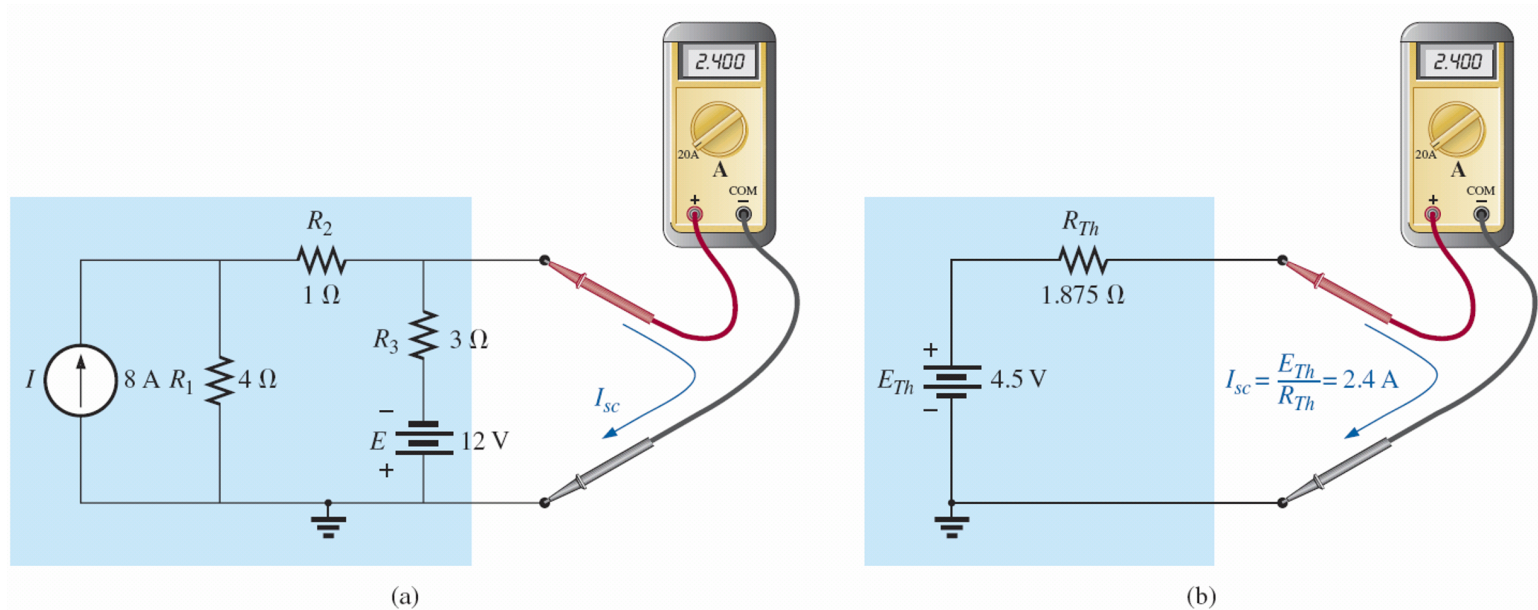


FIG. 9.63 Determining R_{Th} using the short-circuit current: (a) actual network; (b) Thévenin equivalent.

NORTON'S THEOREM

- In Section 8.3, we learned that every voltage source with a series internal resistance has a current source equivalent.
- The current source equivalent can be determined by Norton's theorem. It can also be found through the conversions of Section 8.3.

NORTON'S THEOREM

- The theorem states the following:
 - Any two-terminal linear bilateral dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor.

NORTON'S THEOREM

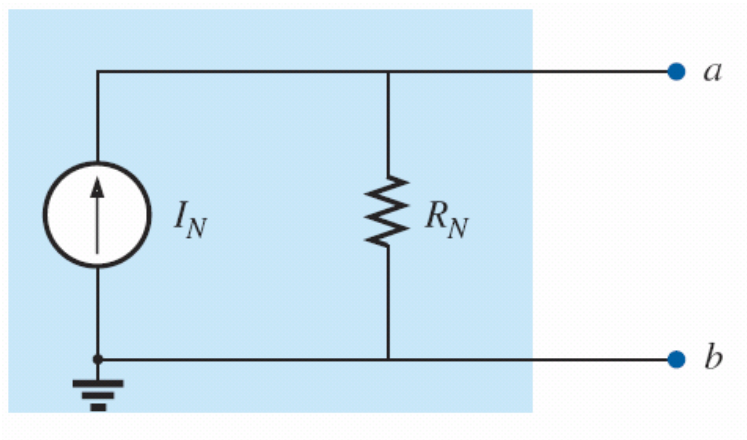


FIG. 9.65 *Norton equivalent circuit.*

NORTON'S THEOREM

Norton's Theorem Procedure

- Preliminary:
 - 1. Remove that portion of the network across which the Norton equivalent circuit is found.
 - 2. Mark the terminals of the remaining two-terminal network.

NORTON'S THEOREM

Norton's Theorem Procedure

- RN:
 - Calculate RN by first setting all sources to zero (voltage sources are replaced with short circuits and current sources with open circuits) and then finding the resultant resistance between the two marked terminals. (If the internal resistance of the voltage and/or current sources is included in the original network, it must remain when the sources are set to zero.)

NORTON'S THEOREM

Norton's Theorem Procedure

- Since $R_N = R_{Th}$, the procedure and value obtained using the approach described for Thévenin's theorem will determine the proper value of R_N .
- I_N :
 - Calculate I_N by first returning all sources to their original position and then finding the short-circuit current between the marked terminals.

NORTON'S THEOREM

Norton's Theorem Procedure

- It is the same current that would be measured by an ammeter placed between the marked terminals.
- Conclusion:
 - Draw the Norton equivalent circuit with the portion of the circuit previously removed replaced between the terminals of the equivalent circuit.

NORTON'S THEOREM

Norton's Theorem Procedure

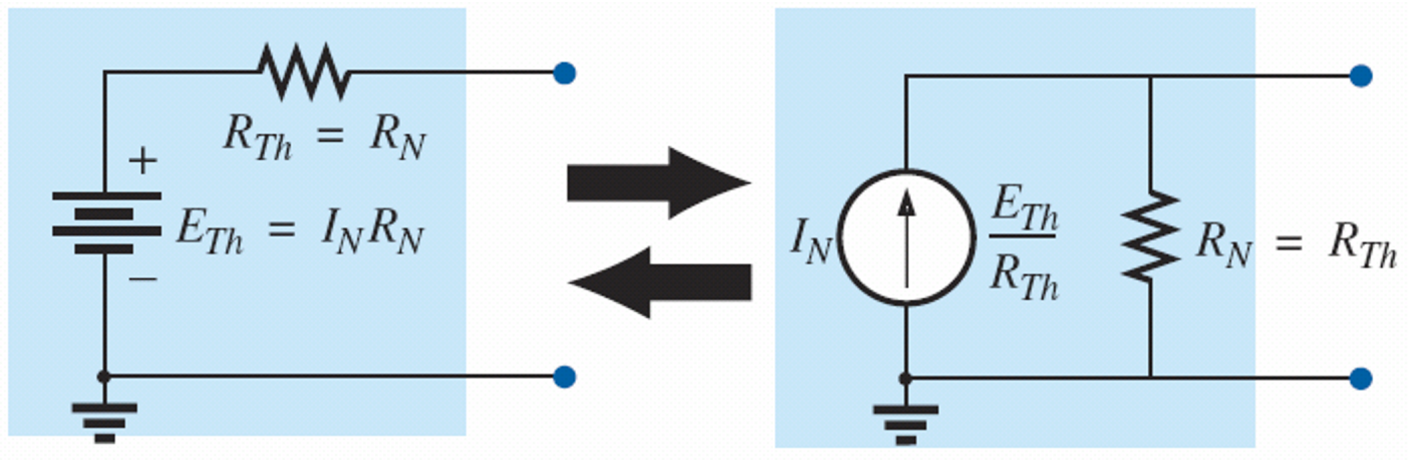


FIG. 9.66 *Converting between Thévenin and Norton equivalent circuits.*

NORTON'S THEOREM

Norton's Theorem Procedure

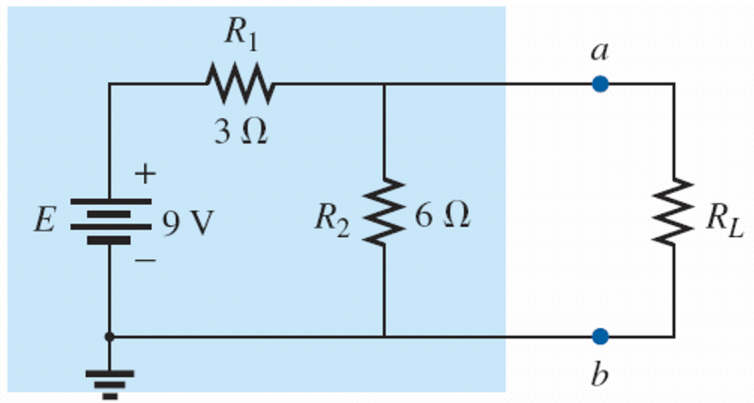


FIG. 9.67
Example 9.12.

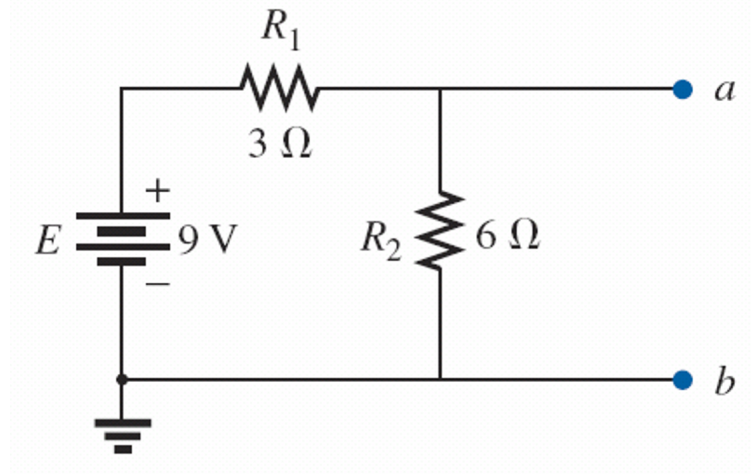


FIG. 9.68 *Identifying the terminals of particular interest for the network in Fig. 9.67.*

NORTON'S THEOREM

Norton's Theorem Procedure

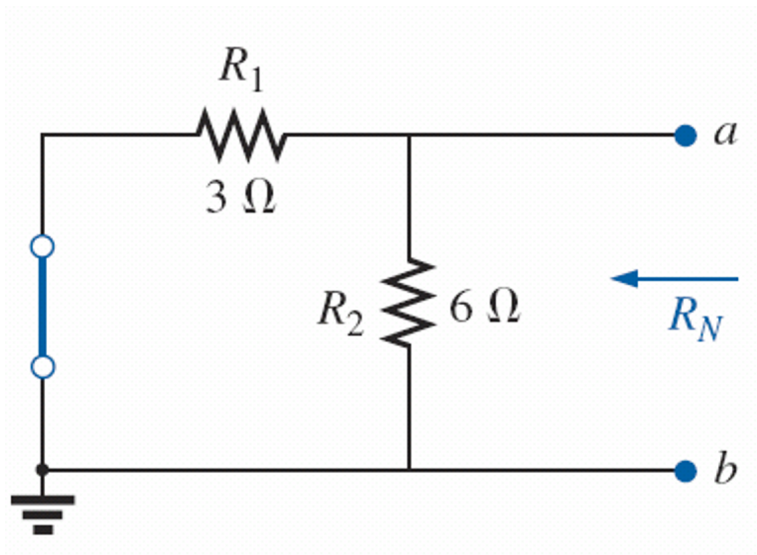


FIG. 9.69 *Determining R_N for the network in Fig. 9.68.*

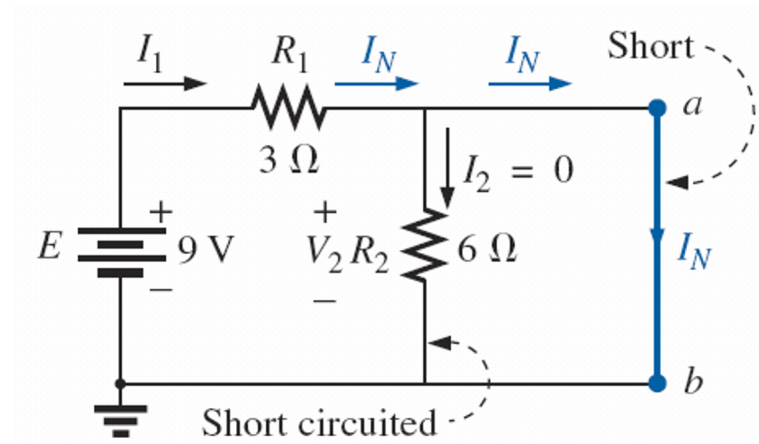


FIG. 9.70
Determining I_N for the network in Fig. 9.68.

NORTON'S THEOREM

Norton's Theorem Procedure

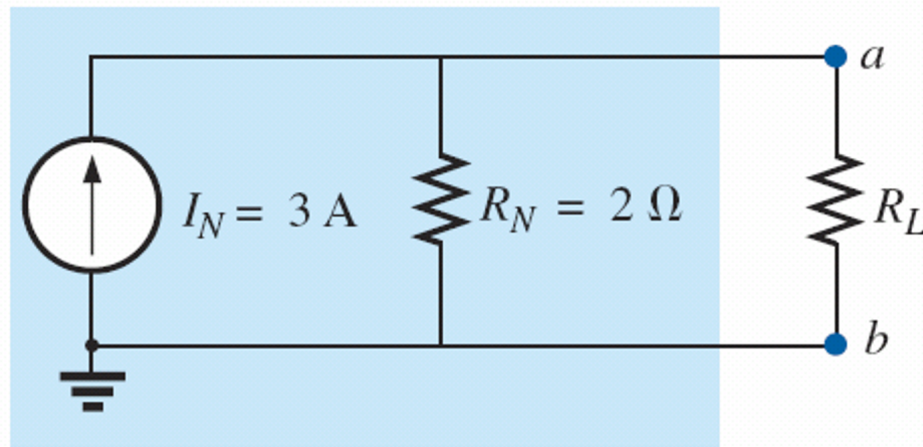


FIG. 9.71 *Substituting the Norton equivalent circuit for the network external to the resistor R_L in Fig. 9.67.*

NORTON'S THEOREM

Norton's Theorem Procedure

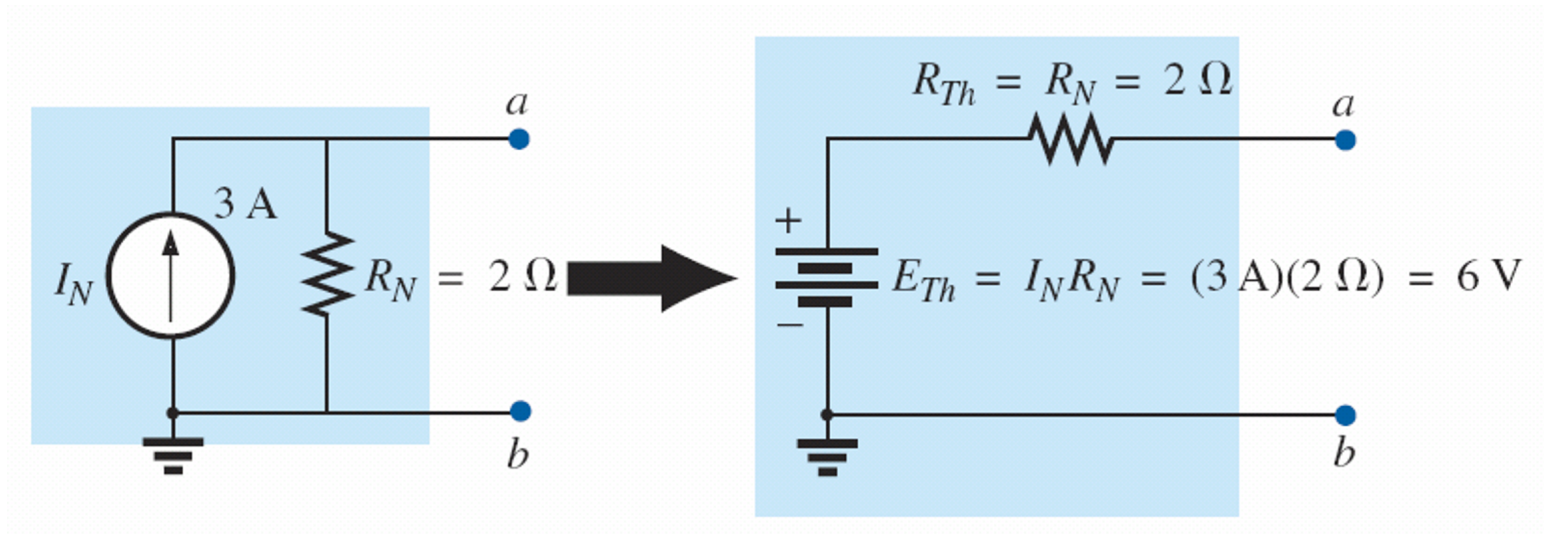


FIG. 9.72 Converting the Norton equivalent circuit in Fig. 9.71 to a Thévenin equivalent circuit.

NORTON'S THEOREM

Norton's Theorem Procedure

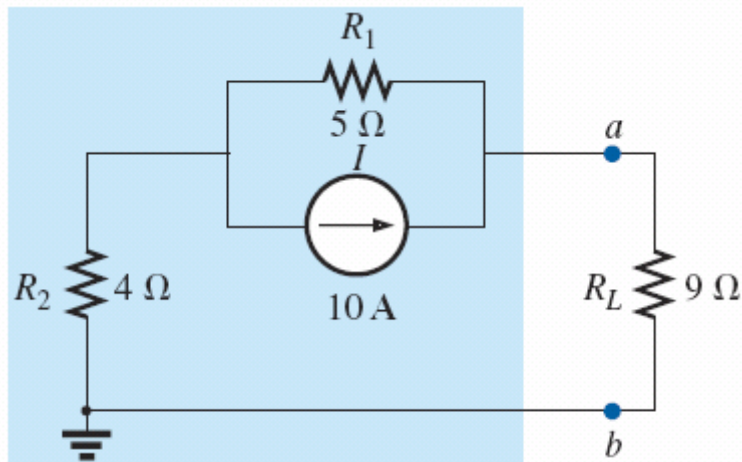


FIG. 9.73
Example 9.13.

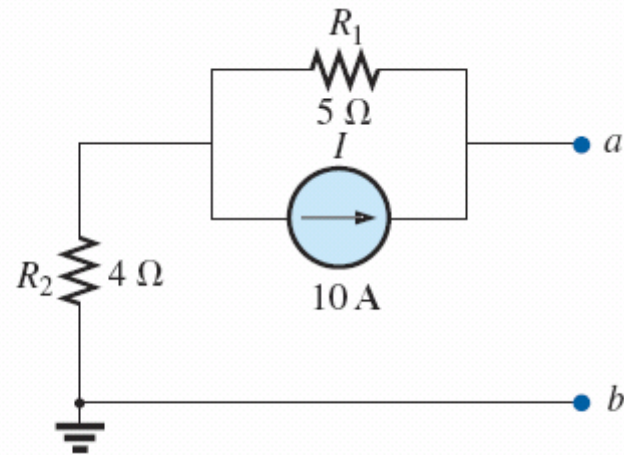


FIG. 9.74 *Identifying the terminals of particular interest for the network in Fig. 9.73.*

NORTON'S THEOREM

Norton's Theorem Procedure

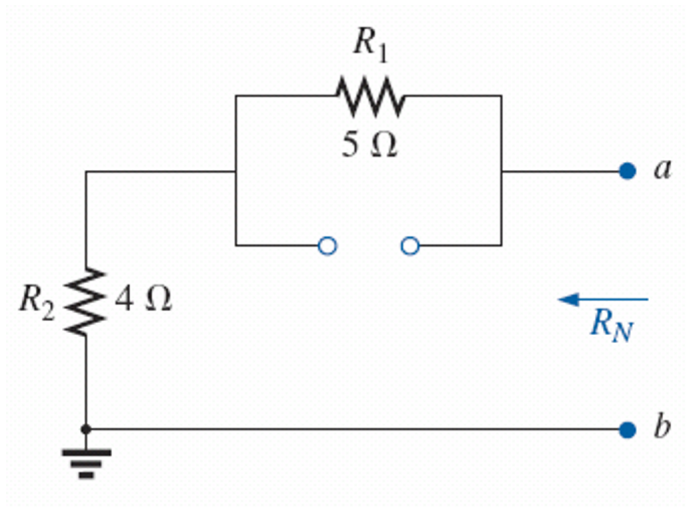


FIG. 9.75 *Determining R_N for the network in Fig. 9.74.*

NORTON'S THEOREM

Norton's Theorem Procedure

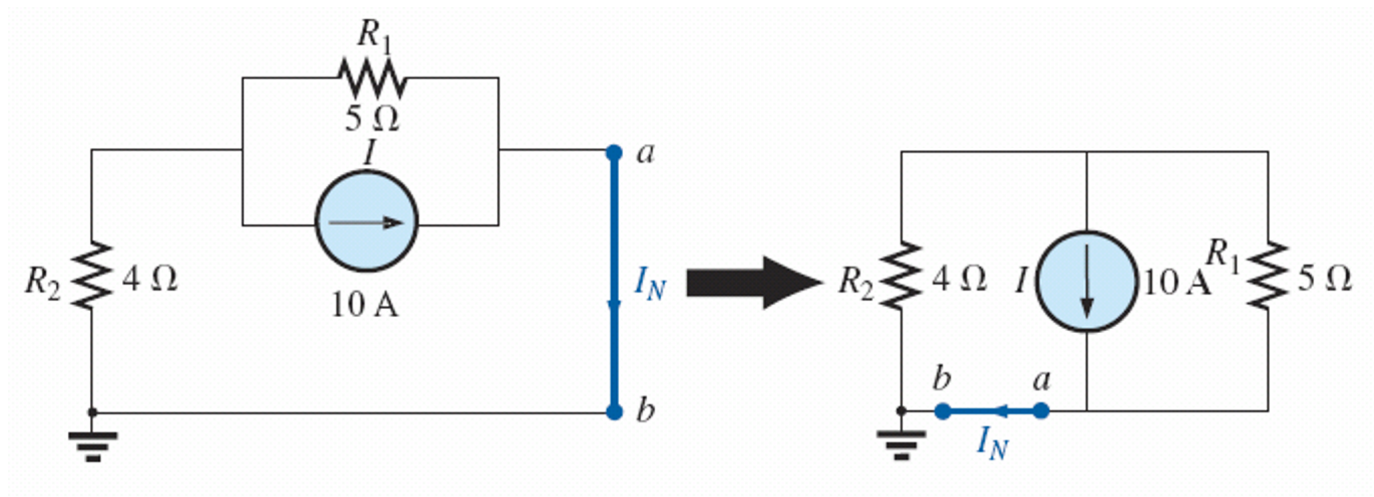


FIG. 9.76 *Determining I_N for the network in Fig. 9.74.*

NORTON'S THEOREM

Norton's Theorem Procedure

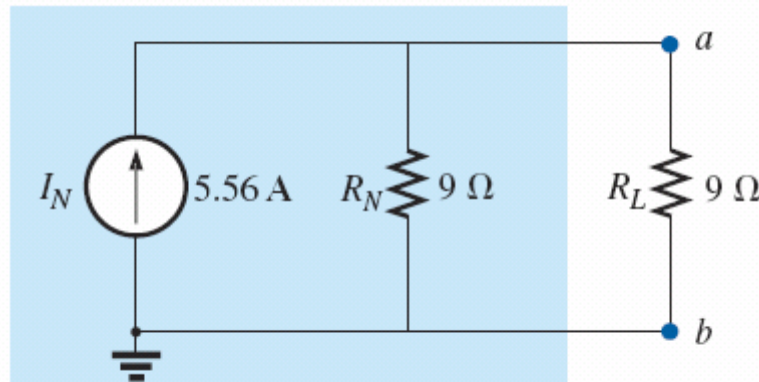


FIG. 9.77 *Substituting the Norton equivalent circuit for the network external to the resistor R_L in Fig. 9.73.*

NORTON'S THEOREM

Norton's Theorem Procedure

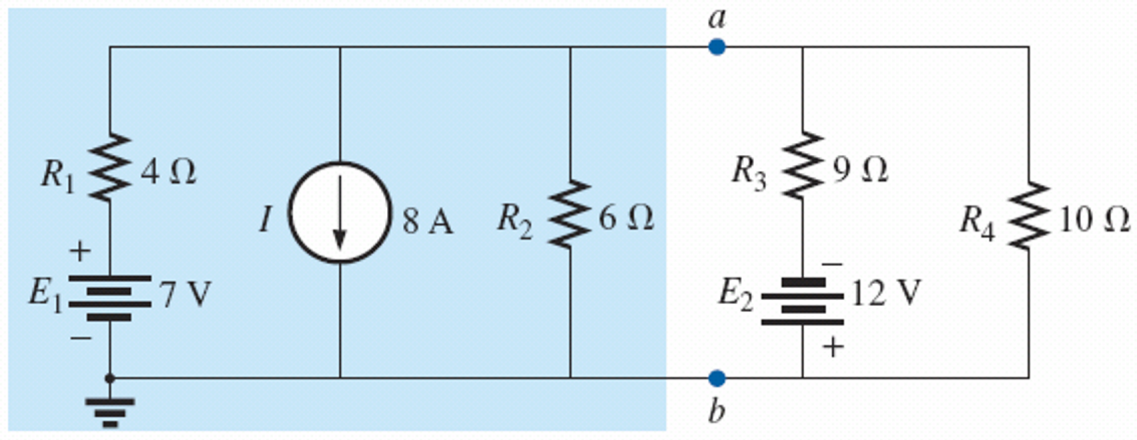


FIG. 9.78
Example 9.14.

NORTON'S THEOREM

Norton's Theorem Procedure

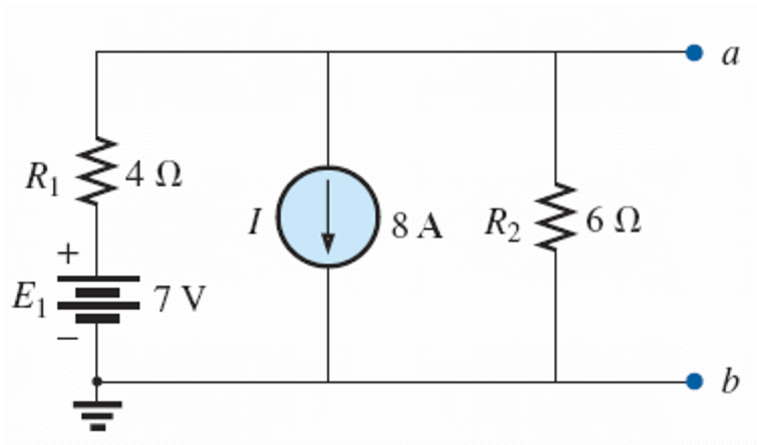


FIG. 9.79 *Identifying the terminals of particular interest for the network in Fig. 9.78.*

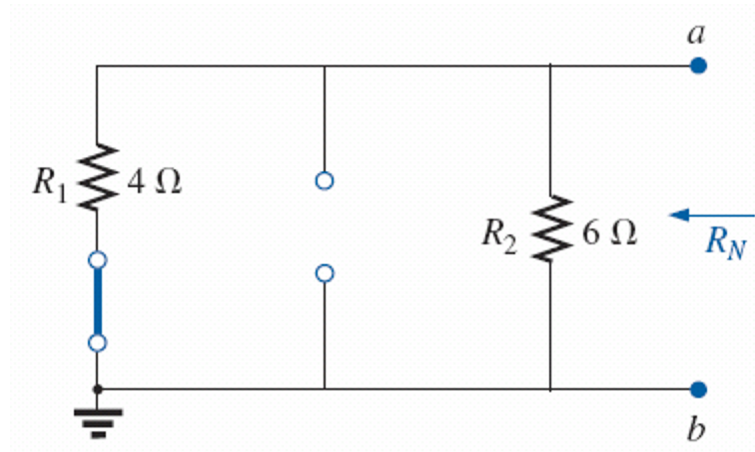


FIG. 9.80 *Determining R_N for the network in Fig. 9.79.*

NORTON'S THEOREM

Norton's Theorem Procedure

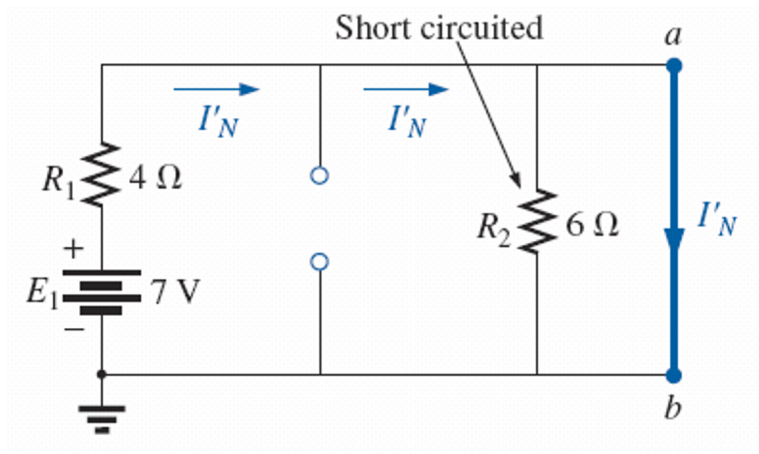


FIG. 9.81 *Determining the contribution to I_N from the voltage source E_1 .*

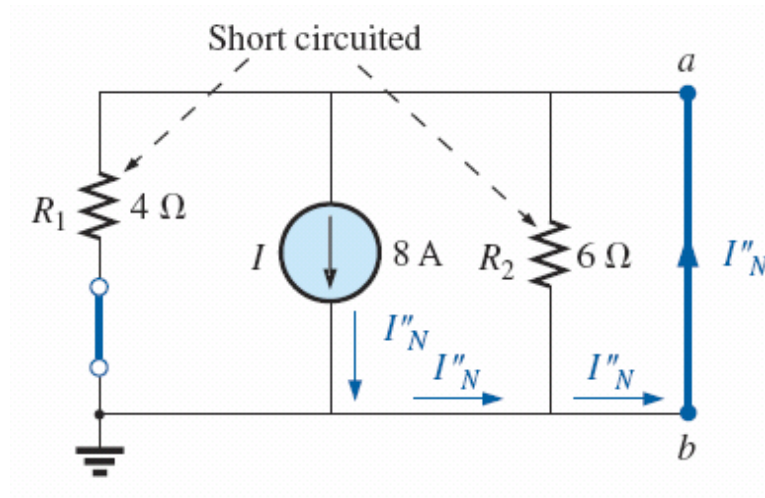


FIG. 9.82 *Determining the contribution to I_N from the current source I .*

NORTON'S THEOREM

Norton's Theorem Procedure

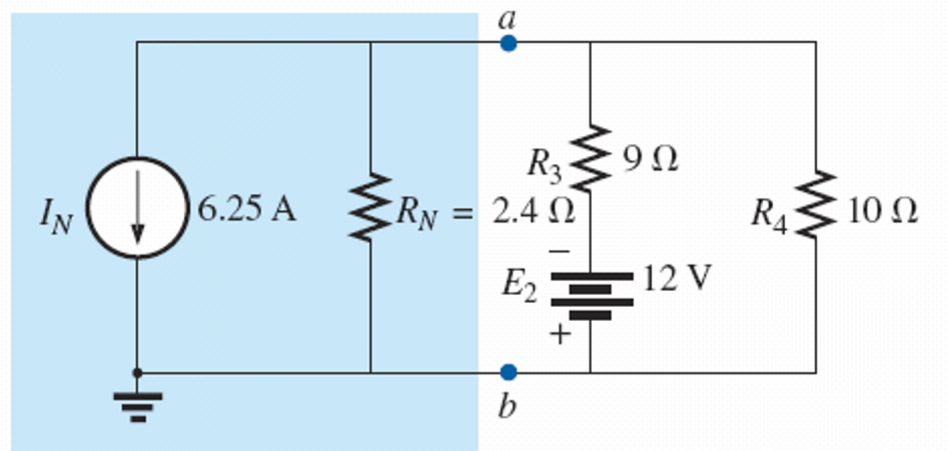


FIG. 9.83 *Substituting the Norton equivalent circuit for the network to the left of terminals a - b in Fig. 9.78.*

NORTON'S THEOREM

Experimental Procedure

- The Norton current is measured in the same way as described for the short-circuit current (I_{sc}) for the Thévenin network.
- Since the Norton and Thévenin resistances are the same, the same procedures can be followed as described for the Thévenin network.

MAXIMUM POWER TRANSFER THEOREM

- When designing a circuit, it is often important to be able to answer one of the following questions:
 - What load should be applied to a system to ensure that the load is receiving maximum power from the system?

MAXIMUM POWER TRANSFER THEOREM

- Conversely:
 - For a particular load, what conditions should be imposed on the source to ensure that it will deliver the maximum power available?

MAXIMUM POWER TRANSFER THEOREM

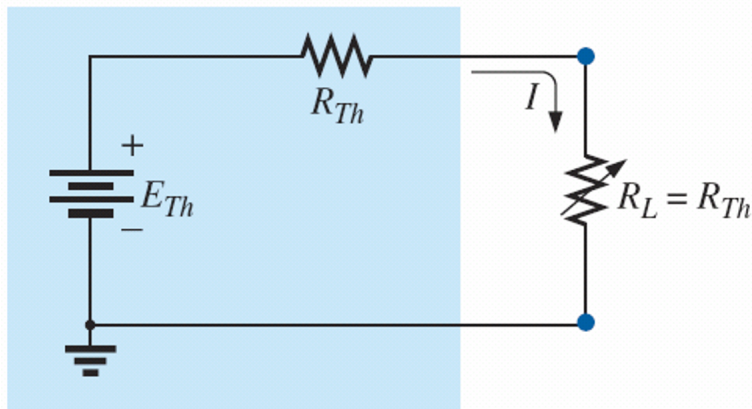


FIG. 9.84 *Defining the conditions for maximum power to a load using the Thévenin equivalent circuit.*

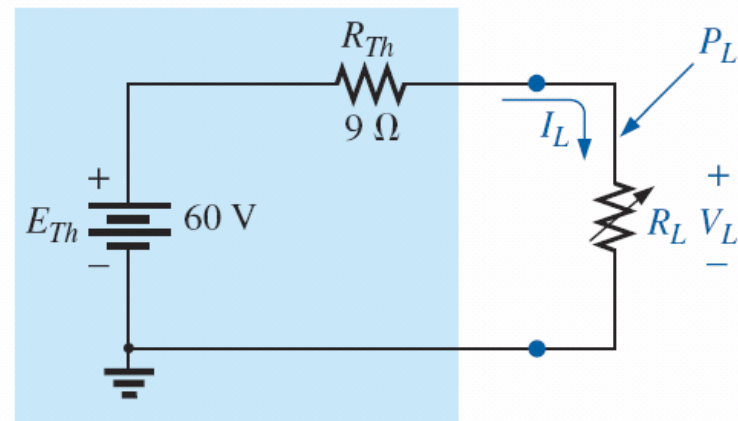


FIG. 9.85 *Thévenin equivalent network to be used to validate the maximum power transfer theorem.*

MAXIMUM POWER TRANSFER THEOREM

$R_L (\Omega)$	$P_L (W)$	$I_L (A)$	$V_L (V)$
0.1	4.35	6.60	0.66
0.2	8.51	6.52	1.30
0.5	19.94	6.32	3.16
1	36.00	6.00	6.00
2	59.50	5.46	10.91
3	75.00	5.00	15.00
4	85.21	4.62	18.46
5	91.84	4.29	21.43
6	96.00	4.00	24.00
7	98.44	3.75	26.25
8	99.65	3.53	28.23
9 (R_{Th})	100.00 (Maximum)	3.33 ($I_{max}/2$)	30.00 ($E_{Th}/2$)
10	99.72	3.16	31.58
11	99.00	3.00	33.00
12	97.96	2.86	34.29
13	96.69	2.73	35.46
14	95.27	2.61	36.52
15	93.75	2.50	37.50
16	92.16	2.40	38.40
17	90.53	2.31	39.23
18	88.89	2.22	40.00
19	87.24	2.14	40.71
20	85.61	2.07	41.38
25	77.86	1.77	44.12
30	71.00	1.54	46.15
40	59.98	1.22	48.98
100	30.30	0.55	55.05
500	6.95	0.12	58.94
1000	3.54	0.06	59.47

TABLE 9.1

MAXIMUM POWER TRANSFER THEOREM

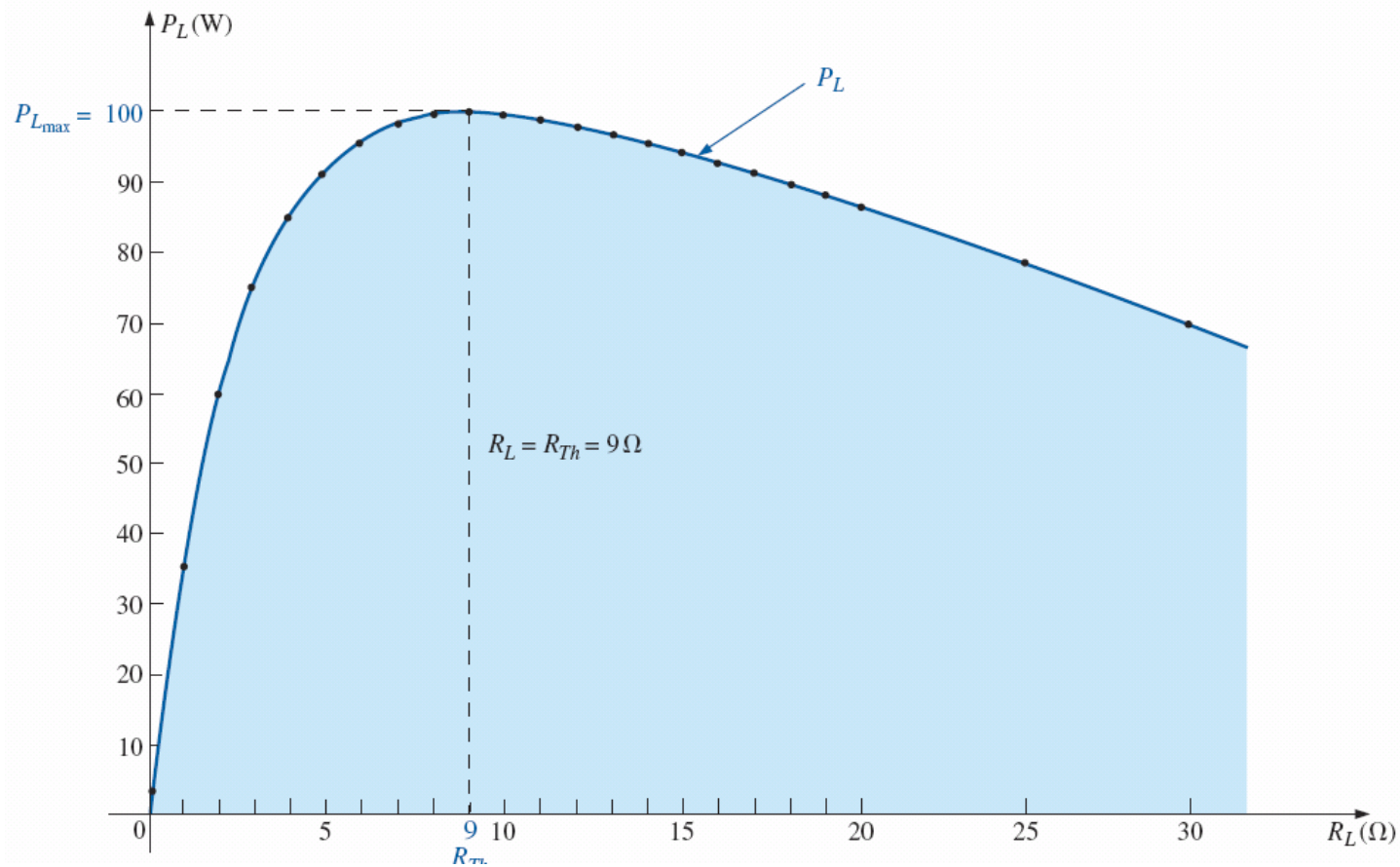


FIG. 9.86 P_L versus R_L for the network in Fig. 9.85.

MAXIMUM POWER TRANSFER THEOREM

- If the load applied is less than the Thévenin resistance, the power to the load will drop off rapidly as it gets smaller. However, if the applied load is greater than the Thévenin resistance, the power to the load will not drop off as rapidly as it increases.

MAXIMUM POWER TRANSFER THEOREM

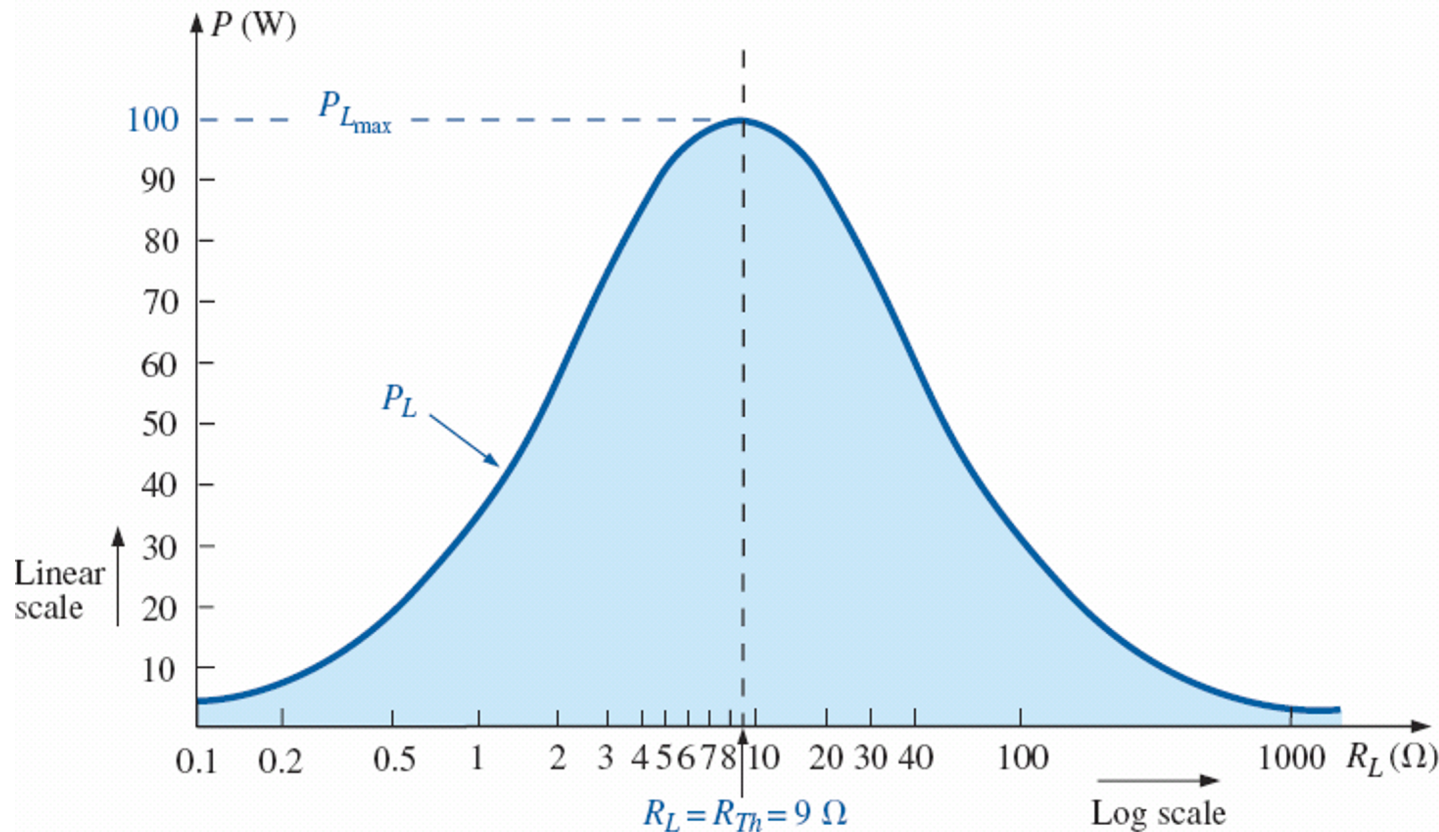


FIG. 9.87 P_L versus R_L for the network in Fig. 9.85.

MAXIMUM POWER TRANSFER THEOREM

- The total power delivered by a supply such as E_{Th} is absorbed by both the Thévenin equivalent resistance and the load resistance. Any power delivered by the source that does not get to the load is lost to the Thévenin resistance.

MAXIMUM POWER TRANSFER THEOREM

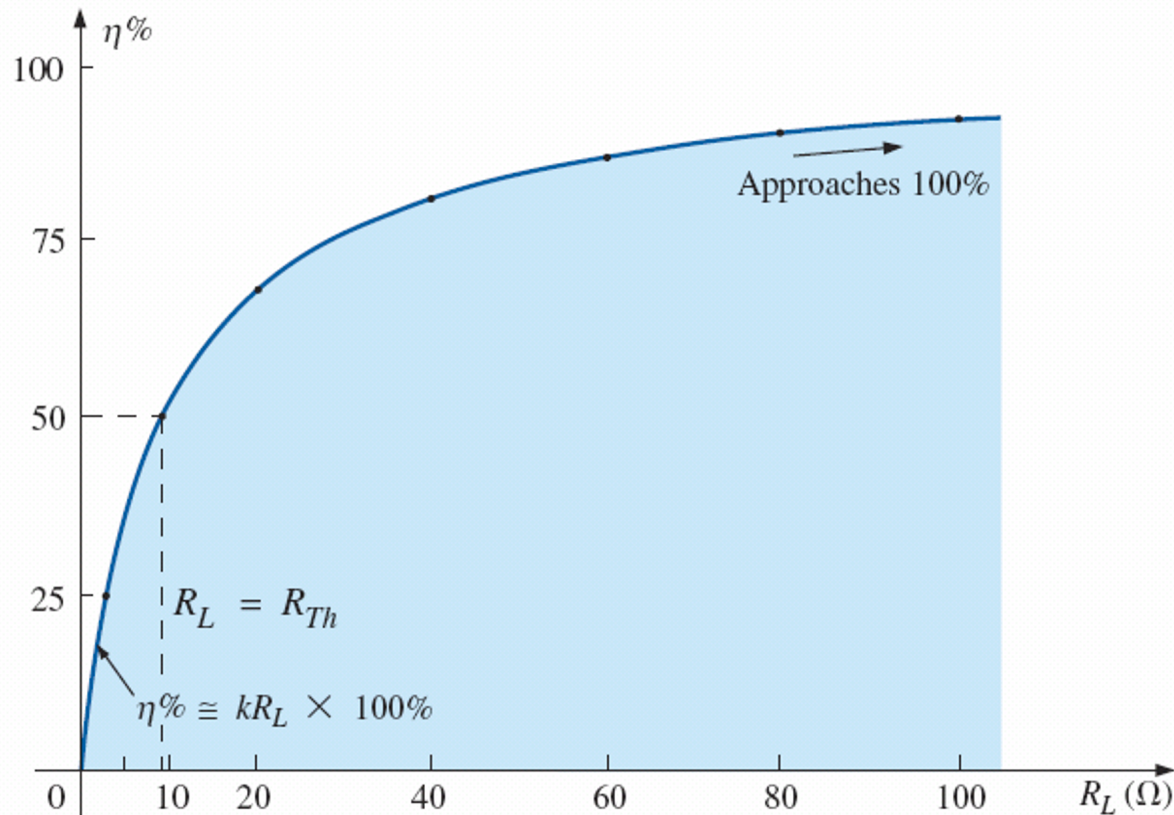


FIG. 9.88 *Efficiency of operation versus increasing values of R_L .*

MAXIMUM POWER TRANSFER THEOREM

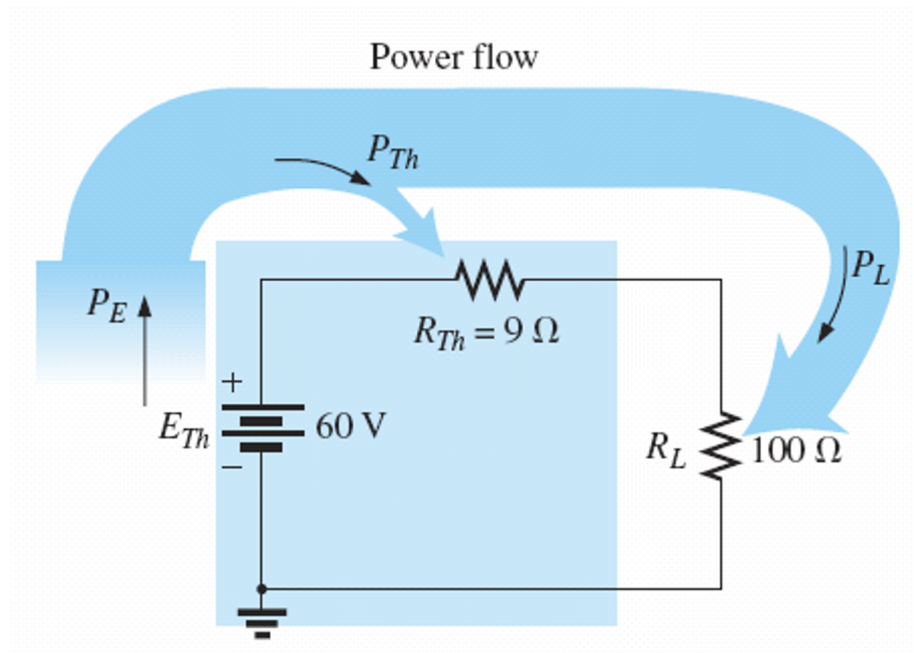


FIG. 9.89 *Examining a circuit with high efficiency but a relatively low level of power to the load.*

MAXIMUM POWER TRANSFER THEOREM

- If efficiency is the overriding factor, then the load should be much larger than the internal resistance of the supply. If maximum power transfer is desired and efficiency less of a concern, then the conditions dictated by the maximum power transfer theorem should be applied.

MAXIMUM POWER TRANSFER THEOREM

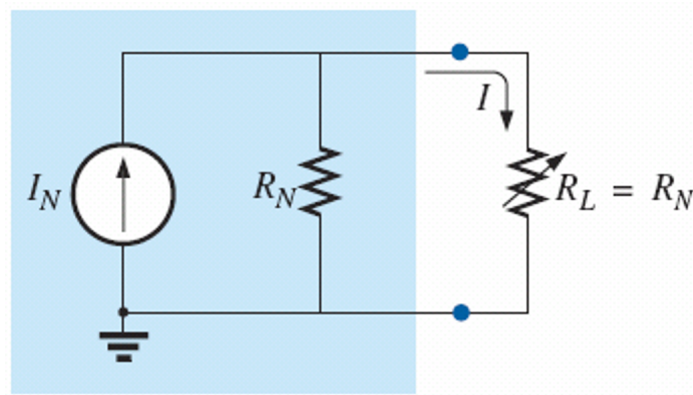


FIG. 9.90 *Defining the conditions for maximum power to a load using the Norton equivalent circuit.*

MAXIMUM POWER TRANSFER THEOREM

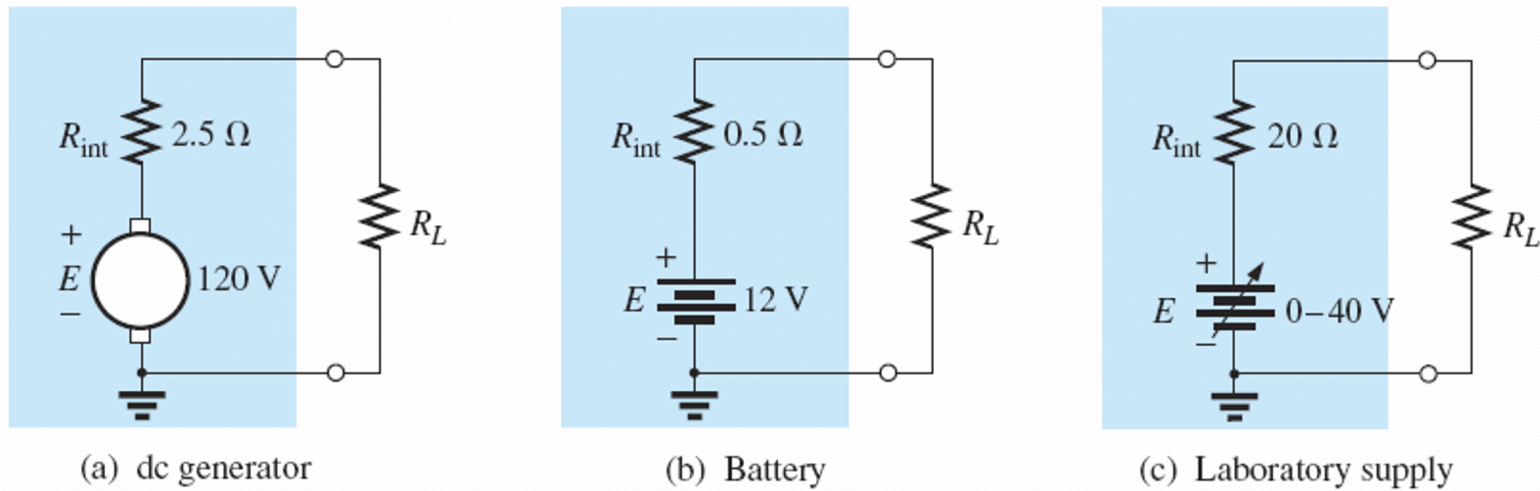


FIG. 9.91
Example 9.15.

MAXIMUM POWER TRANSFER THEOREM

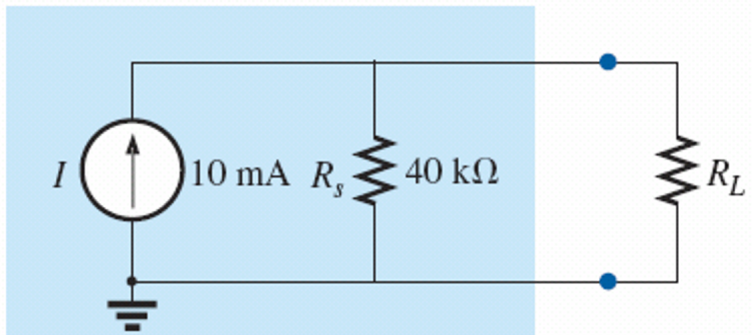
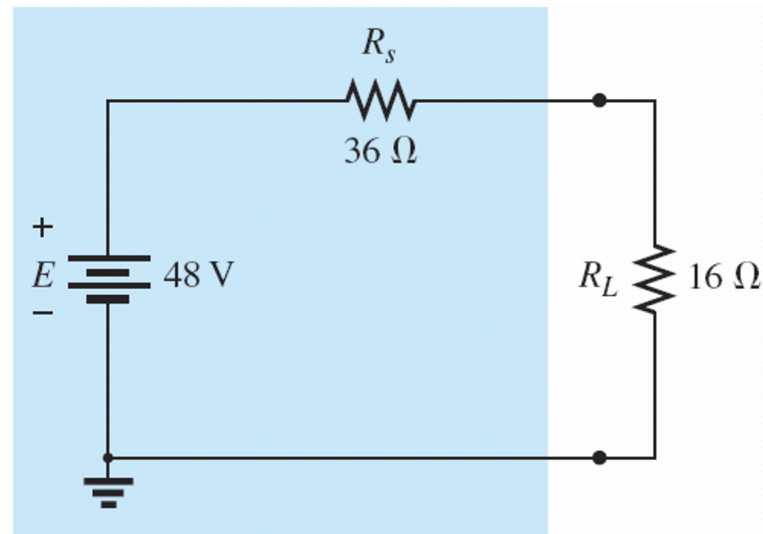


FIG. 9.92

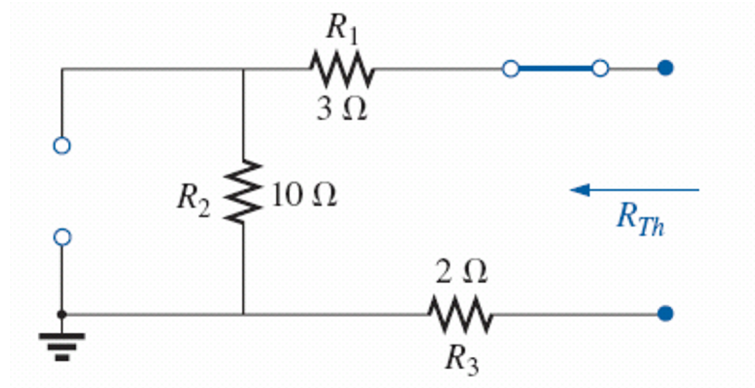
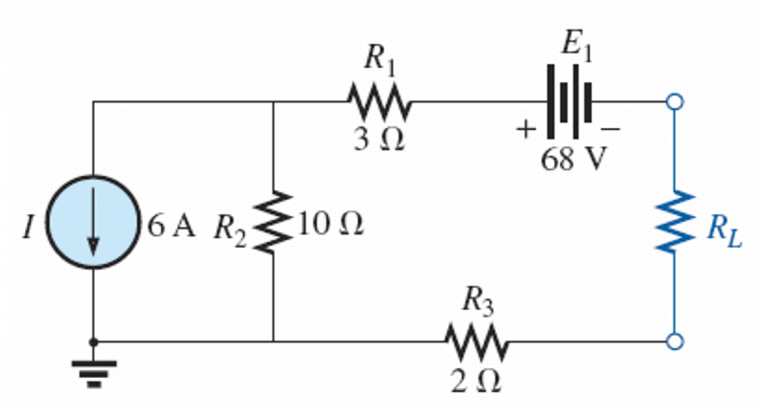
Example 9.16.



dc supply

FIG. 9.93 *dc supply with a fixed 16Ω load (Example 9.17).*

MAXIMUM POWER TRANSFER THEOREM



MAXIMUM POWER TRANSFER THEOREM

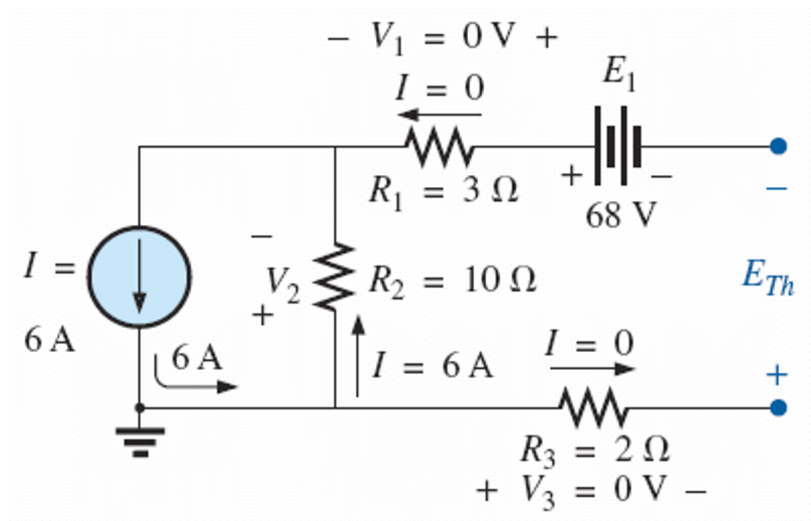


FIG. 9.96 *Determining E_{Th} for the network external to resistor R_L in Fig. 9.94.*

MILLMAN'S THEOREM

- Through the application of Millman's theorem, any number of parallel voltage sources can be reduced to one.
- This permits finding the current through or voltage across RL without having to apply a method such as mesh analysis, nodal analysis, superposition, and so on.

MILLMAN'S THEOREM

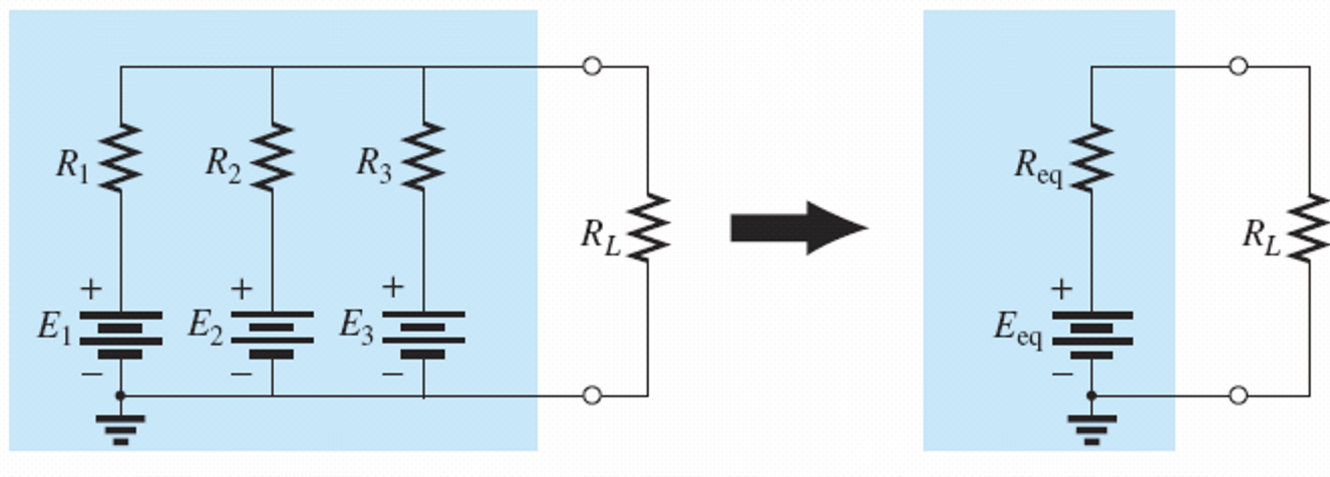


FIG. 9.97 *Demonstrating the effect of applying Millman's theorem.*

MILLMAN'S THEOREM

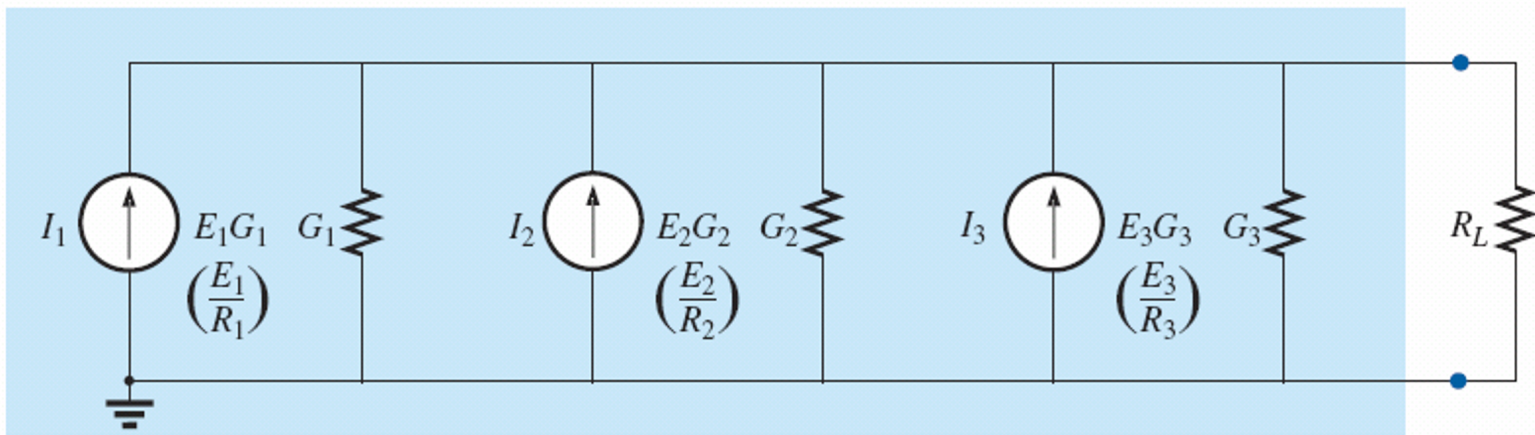


FIG. 9.98 Converting all the sources in Fig. 9.97 to current sources.

MILLMAN'S THEOREM

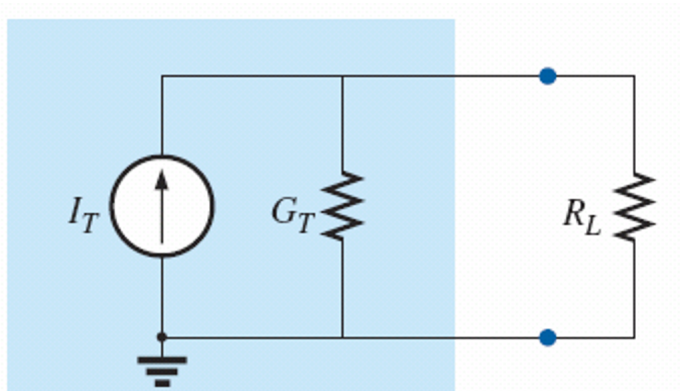


FIG. 9.99 *Reducing all the current sources in Fig. 9.98 to a single current source.*

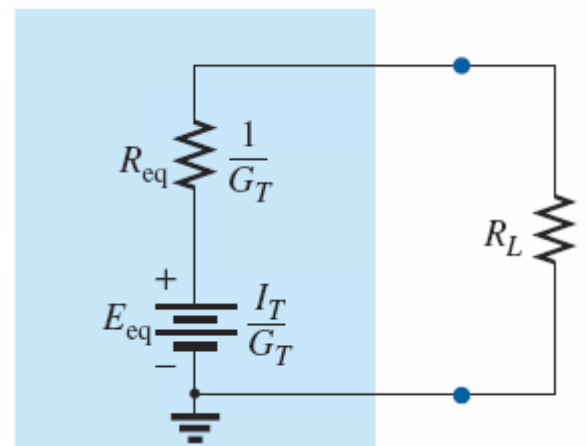


FIG. 9.100 *Converting the current source in Fig. 9.99 to a voltage source.*

MILLMAN'S THEOREM

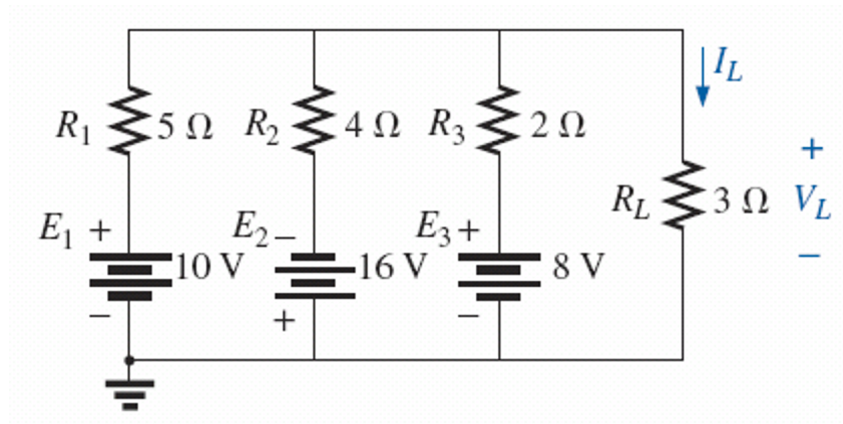


FIG. 9.101
Example 9.19.

MILLMAN'S THEOREM

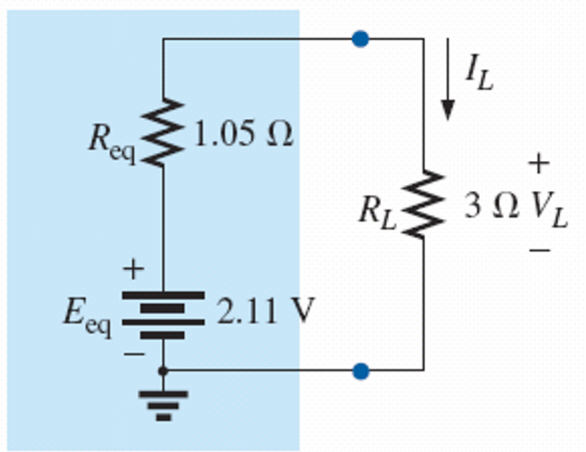


FIG. 9.102 *The result of applying Millman's theorem to the network in Fig. 9.101.*

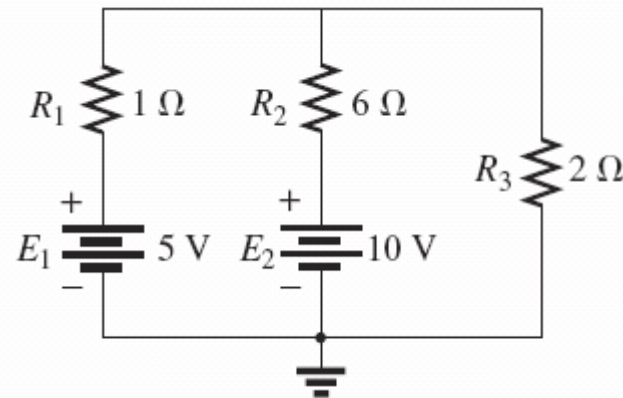


FIG. 9.103
Example 9.20.

MILLMAN'S THEOREM

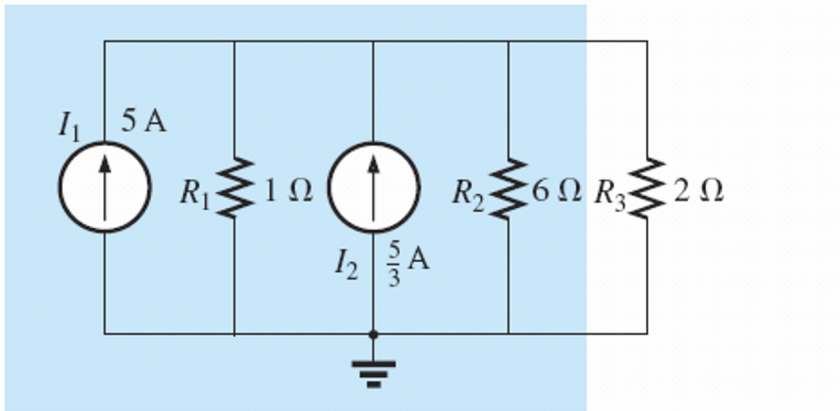


FIG. 9.104 *Converting the sources in Fig. 9.103 to current sources.*

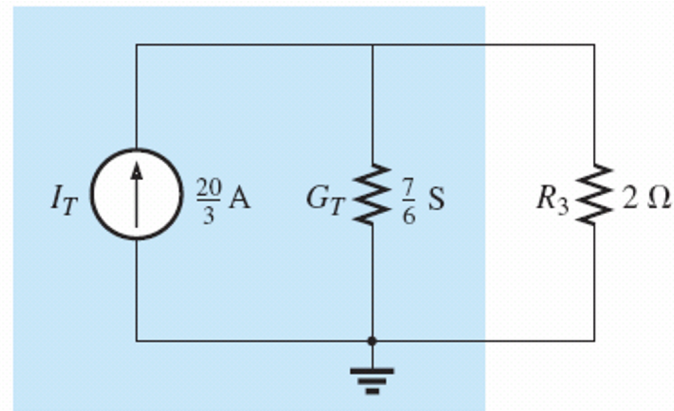


FIG. 9.105 *Reducing the current sources in Fig. 9.104 to a single source.*

MILLMAN'S THEOREM

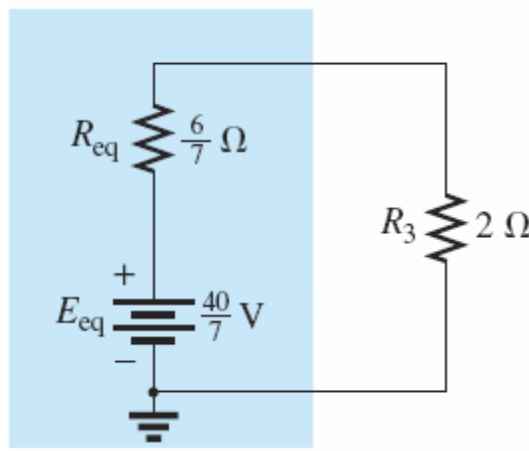


FIG. 9.106

Converting the current source in Fig. 9.105 to a voltage source.

MILLMAN'S THEOREM

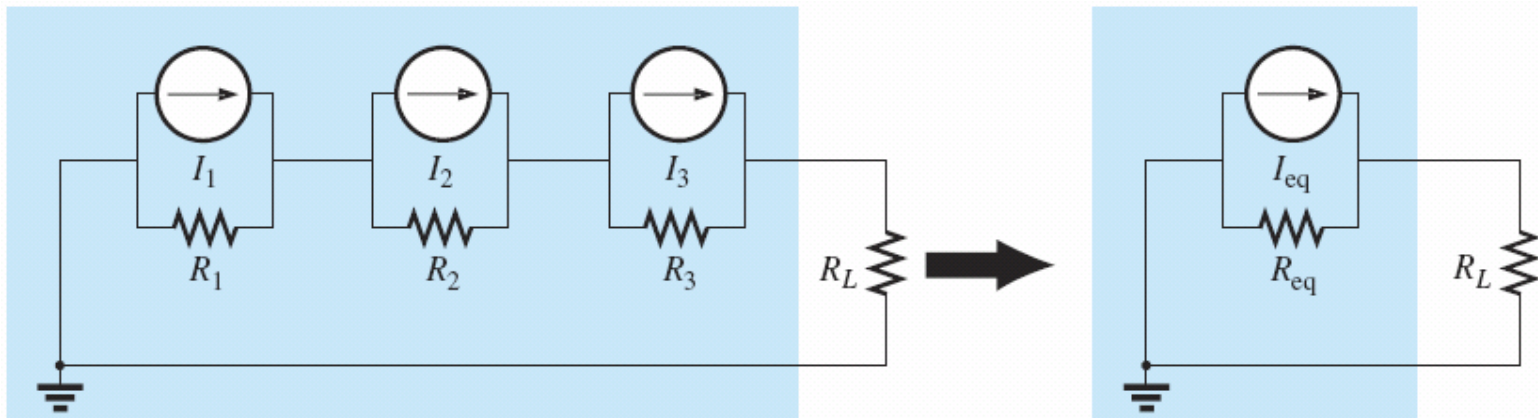


FIG. 9.107 *The dual effect of Millman's theorem.*

SUBSTITUTION THEOREM

- The substitution theorem states the following:
 - If the voltage across and the current through any branch of a dc bilateral network are known, this branch can be replaced by any combination of elements that will maintain the same voltage across and current through the chosen branch.

SUBSTITUTION THEOREM

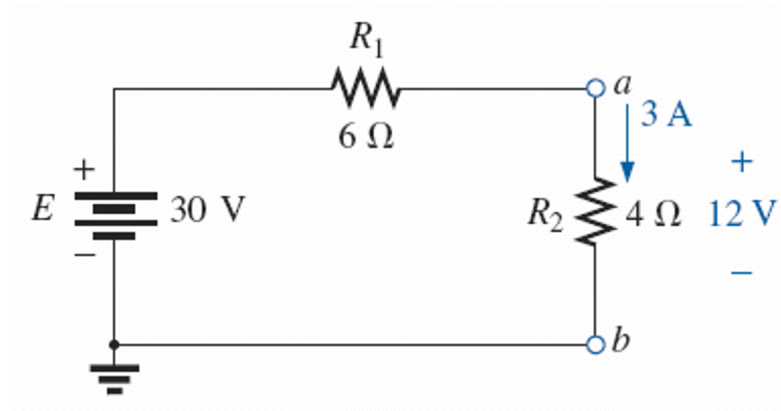


FIG. 9.108 *Demonstrating the effect of the substitution theorem.*

SUBSTITUTION THEOREM

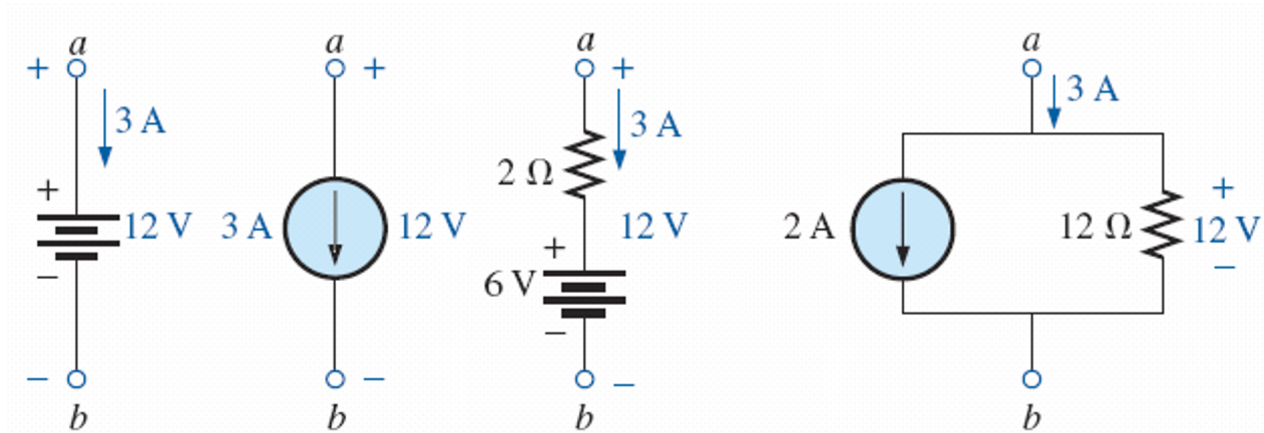


FIG. 9.109 *Equivalent branches for the branch a - b in Fig. 9.108.*

SUBSTITUTION THEOREM

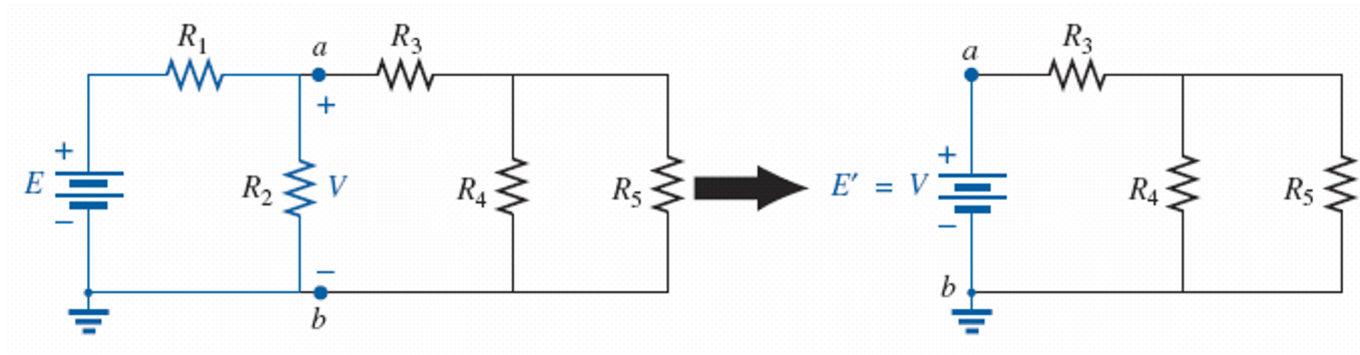


FIG. 9.110 *Demonstrating the effect of knowing a voltage at some point in a complex network.*

SUBSTITUTION THEOREM

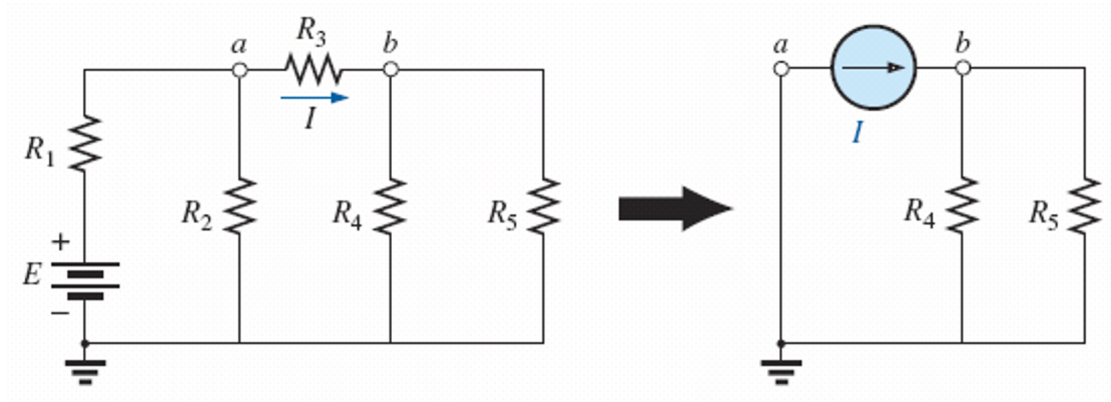


FIG. 9.111 *Demonstrating the effect of knowing a current at some point in a complex network.*

RECIPROCITY THEOREM

- The reciprocity theorem is applicable only to single-source networks.
- It is, therefore, not a theorem used in the analysis of multisource networks described thus far. The theorem states the following:

RECIPROCITY THEOREM

- The current I in any branch of a network due to a single voltage source E anywhere else in the network will equal the current through the branch in which the source was originally located if the source is placed in the branch in which the current I was originally measured.

RECIPROCITY THEOREM

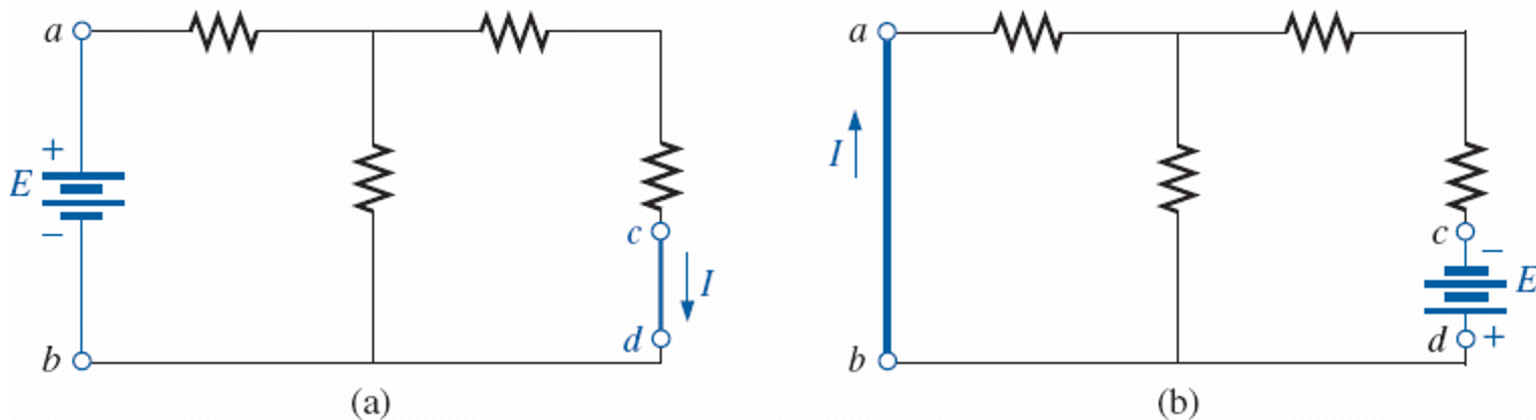


FIG. 9.112 *Demonstrating the impact of the reciprocity theorem.*

RECIPROCITY THEOREM

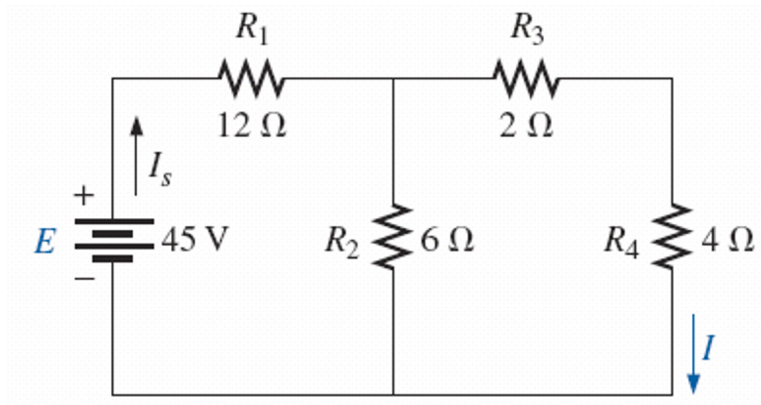


FIG. 9.113 Finding the current I due to a source E .

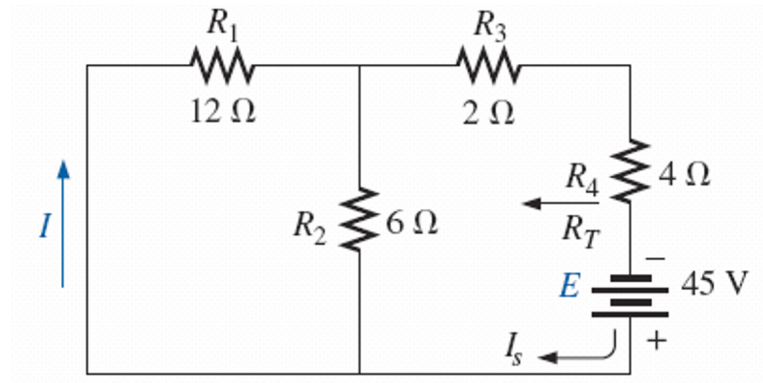


FIG. 9.114
Interchanging the location of E and I of Fig. 9.113 to demonstrate the validity of the reciprocity theorem.

RECIPROCITY THEOREM

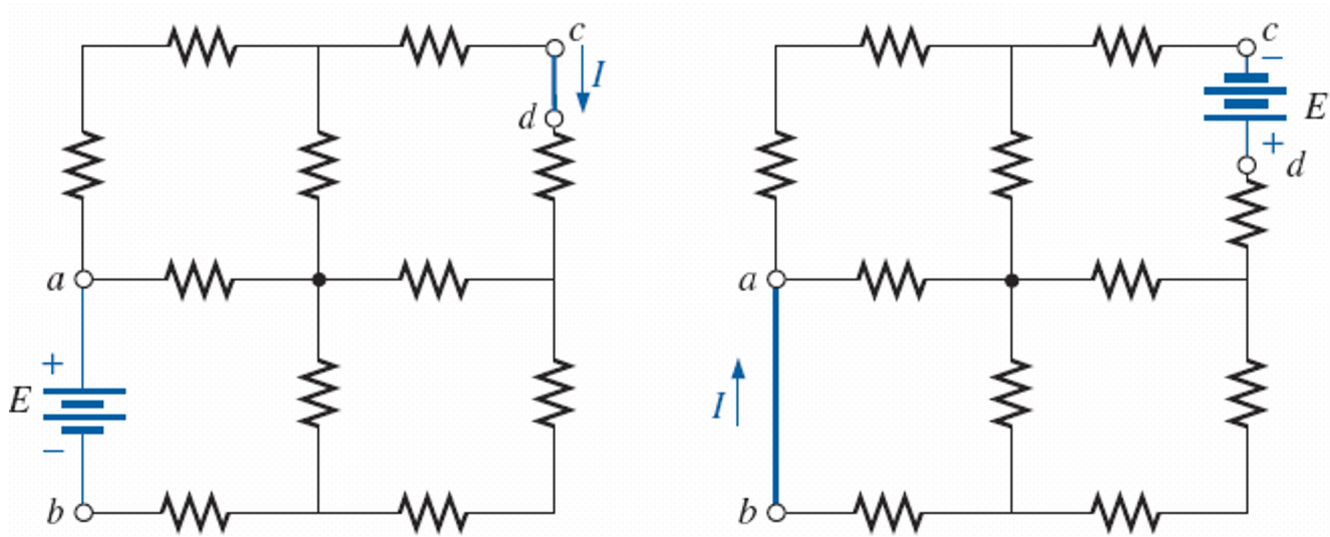


FIG. 9.115 *Demonstrating the power and uniqueness of the reciprocity theorem.*

COMPUTER ANALYSIS

Pspice: Thévenin's Theorem

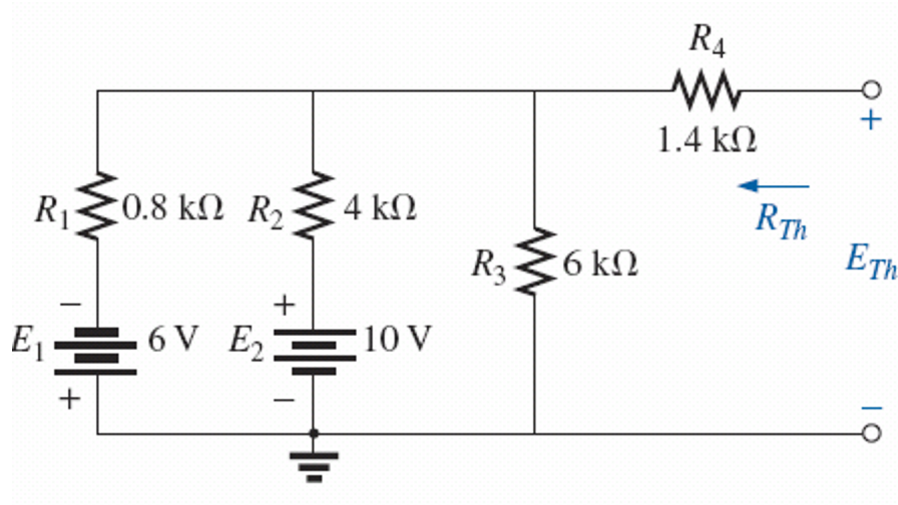


FIG. 9.116 Network to which PSpice is to be applied to determine E_{Th} and R_{Th} .

COMPUTER ANALYSIS

Pspice: Thévenin's Theorem

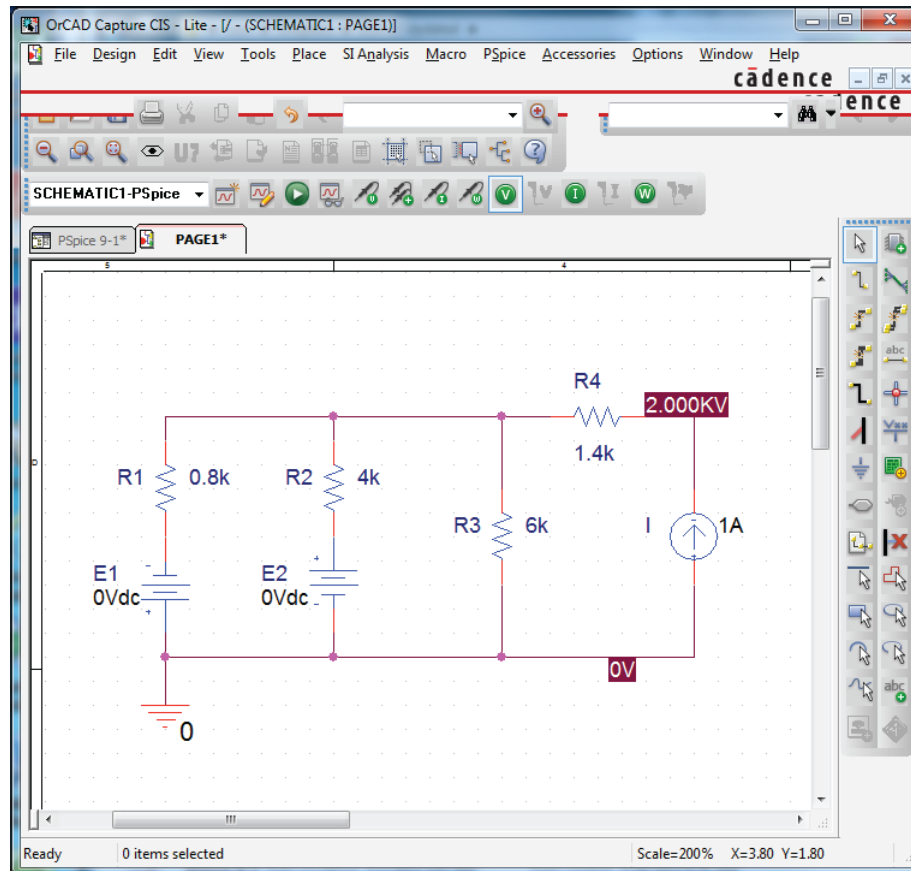


FIG. 9.117 Using PSpice to determine the Thévenin resistance of a network through the application of a 1 A current source.

COMPUTER ANALYSIS

Pspice: Thévenin's Theorem

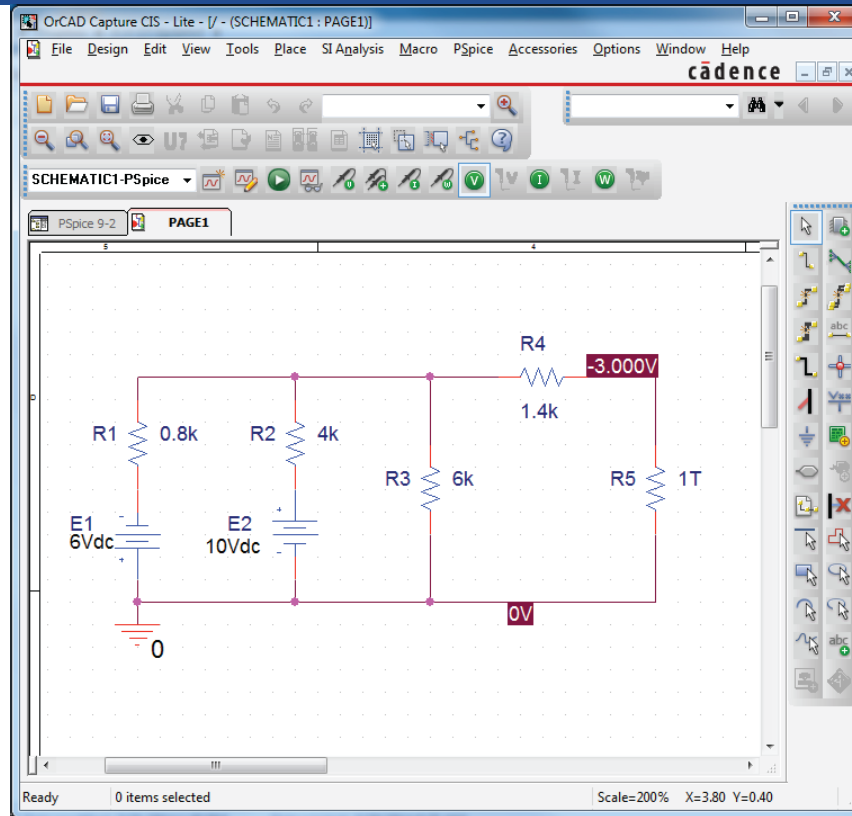


FIG. 9.118 Using PSpice to determine the Thévenin voltage for a network using a very large resistance value to represent the open-circuit condition between the terminals of interest.

COMPUTER ANALYSIS

Pspice: Maximum Power Transfer

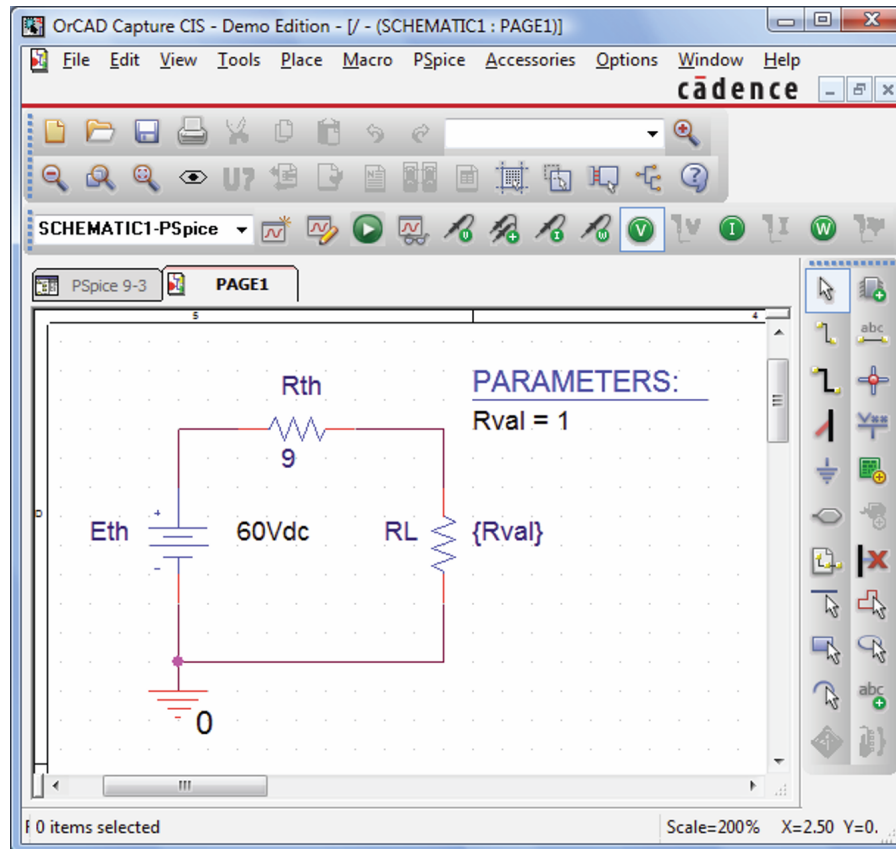


FIG. 9.119 Using PSpice to plot the power to R_L for a range of values for R_L .

COMPUTER ANALYSIS

Pspice: Maximum Power Transfer

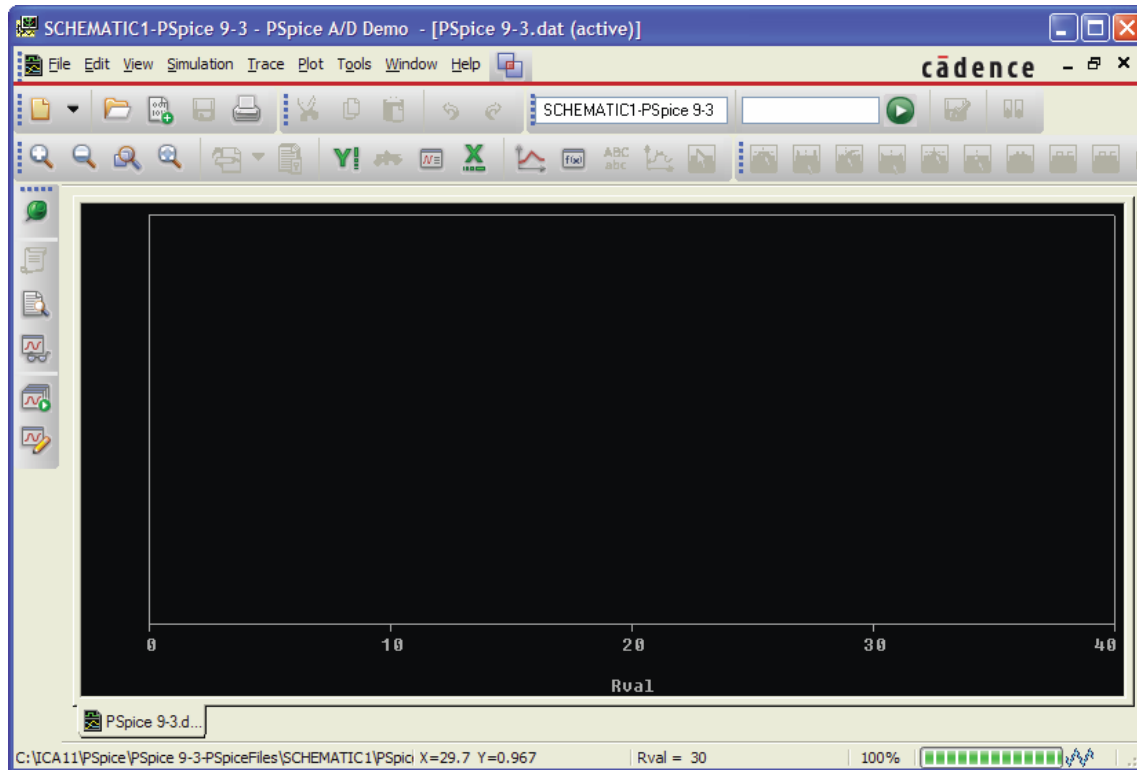


FIG. 9.120 Plot resulting from the dc sweep of R_L for the network in Fig. 9.119 before defining the parameters to be displayed.

COMPUTER ANALYSIS

Pspice: Maximum Power Transfer

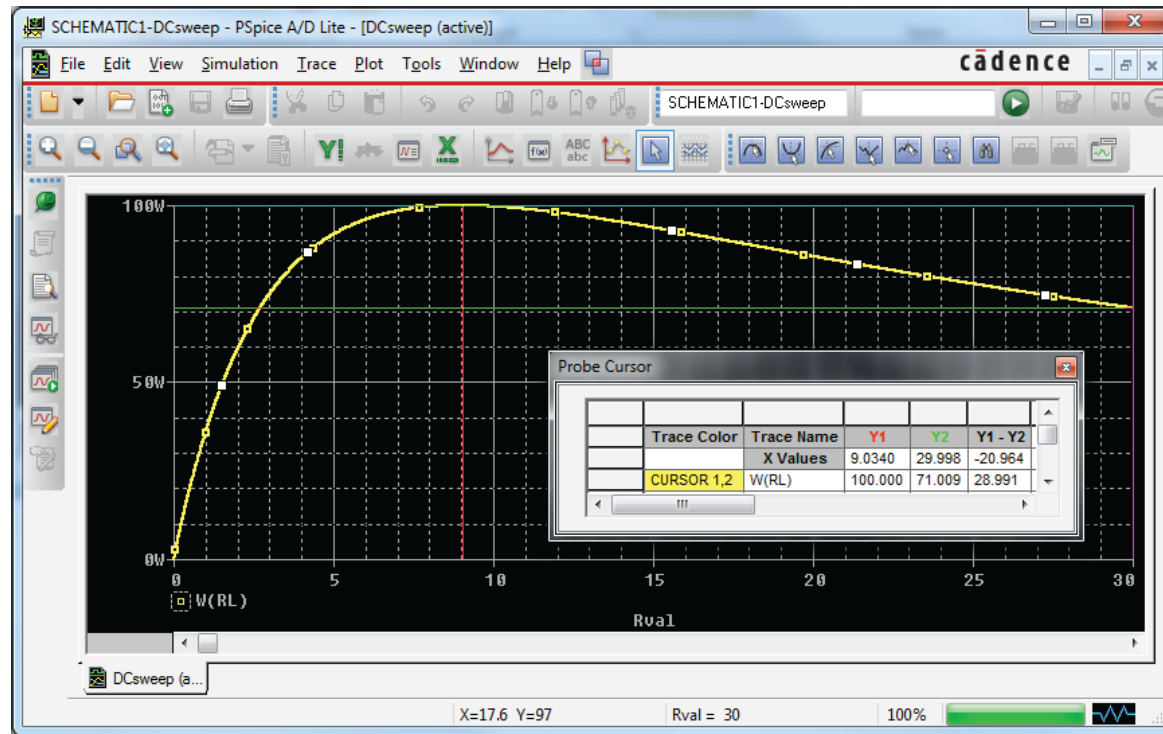


FIG. 9.121 A plot of the power delivered to R_L in Fig. 9.119 for a range of values for R_L extending from 0Ω to 30Ω .

COMPUTER ANALYSIS

Multisim: Superposition

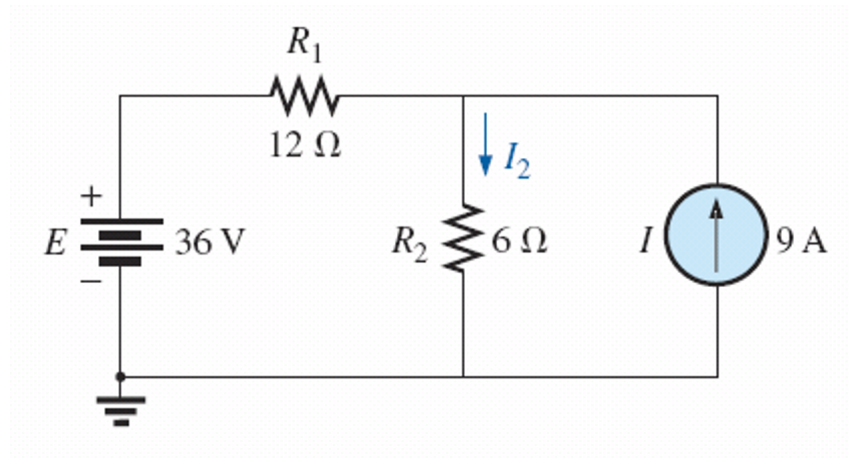


FIG. 9.121 *Applying Multisim to determine the current I_2 using superposition.*

COMPUTER ANALYSIS

Multisim: Superposition

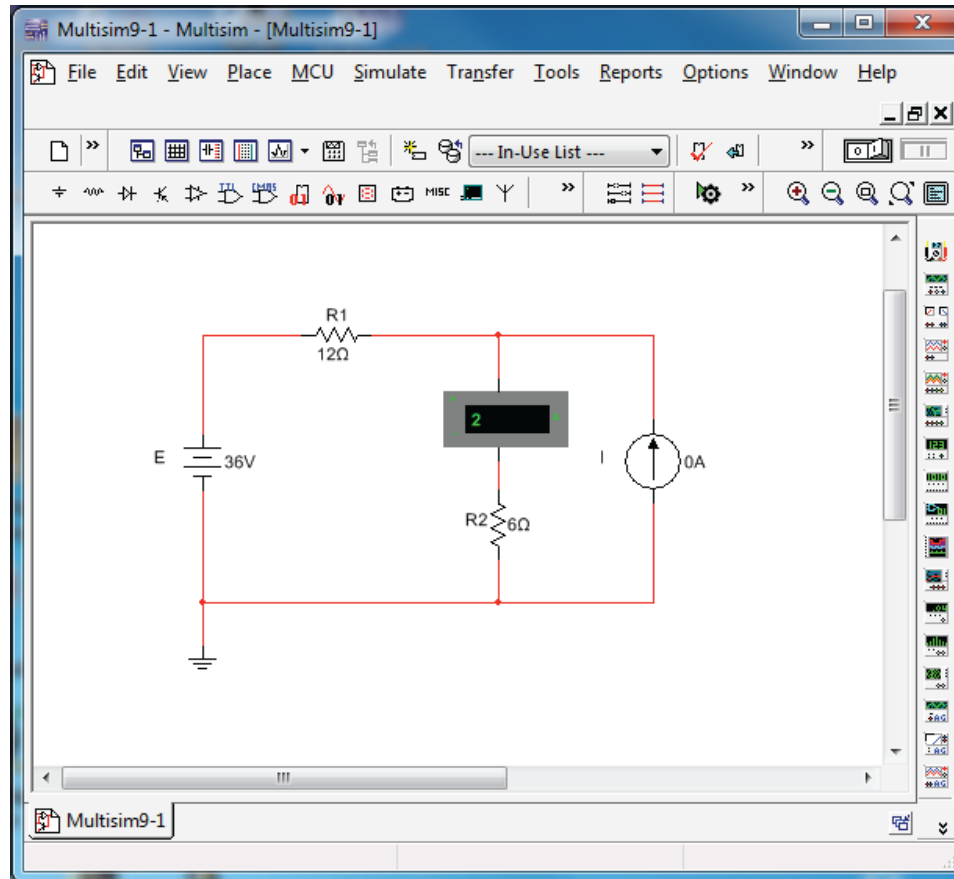


FIG. 9.123 *Using Multisim to determine the contribution of the 36 V voltage source to the current through R2.*

COMPUTER ANALYSIS

Multisim: Superposition

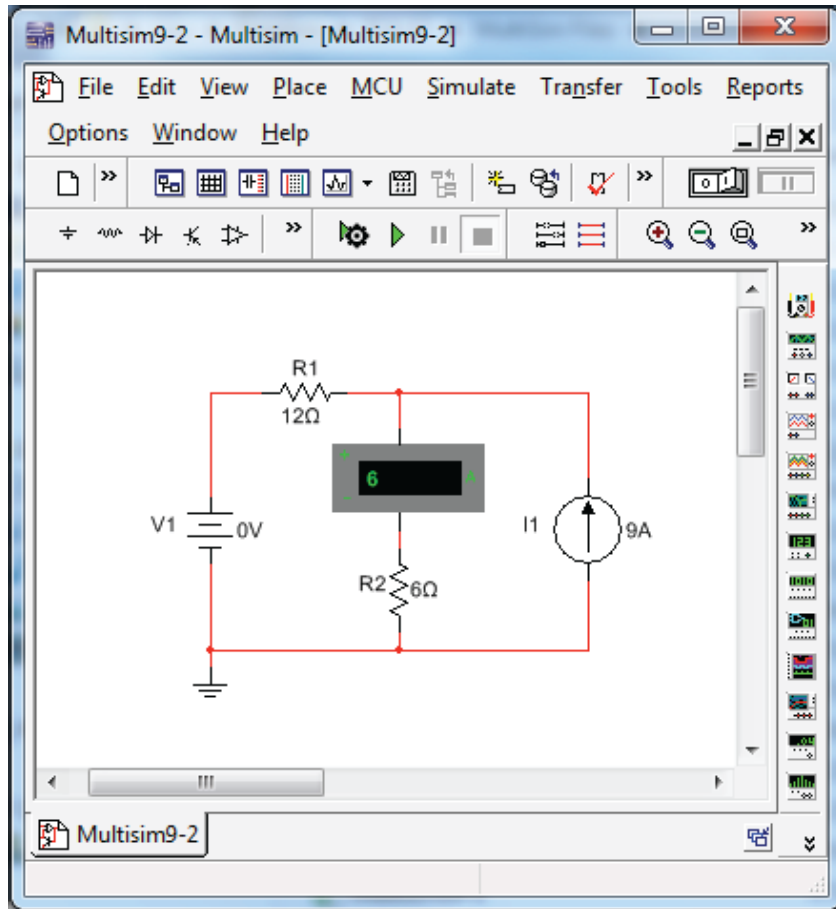
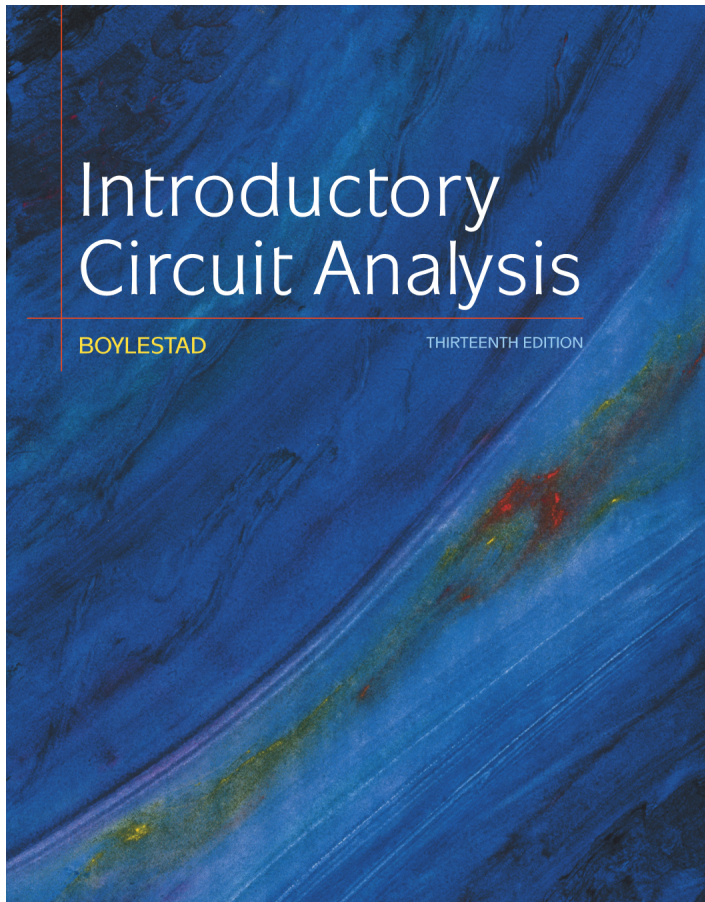


FIG. 9.124 *Using Multisim to determine the contribution of the 9 A current source to the current through R_2 .*

Introductory Circuit Analysis



CHAPTER 10

Capacitors

OBJECTIVES

- Become familiar with the basic construction of a capacitor and the factors that affect its ability to store charge on its plates.
- Be able to determine the transient (time-varying) response of a capacitive network and plot the resulting voltages and currents.

OBJECTIVES

- Understand the impact of combining capacitors in series or parallel and how to read the nameplate data.
- Develop some familiarity with the use of computer methods to analyze networks with capacitive elements.

INTRODUCTION

- The capacitor has a significant impact on the types of networks that you will be able to design and analyze.
- Like the resistor, it is a two-terminal device, but its characteristics are totally different from those of a resistor.
- In fact, the capacitor displays its true characteristics only when a change in the voltage or current is made in the network.

THE ELECTRIC FIELD

- This electric field is represented by electric flux lines, which are drawn to indicate the strength of the electric field at any point around the charged body.
- The denser the lines of flux, the stronger is the electric field.

THE ELECTRIC FIELD

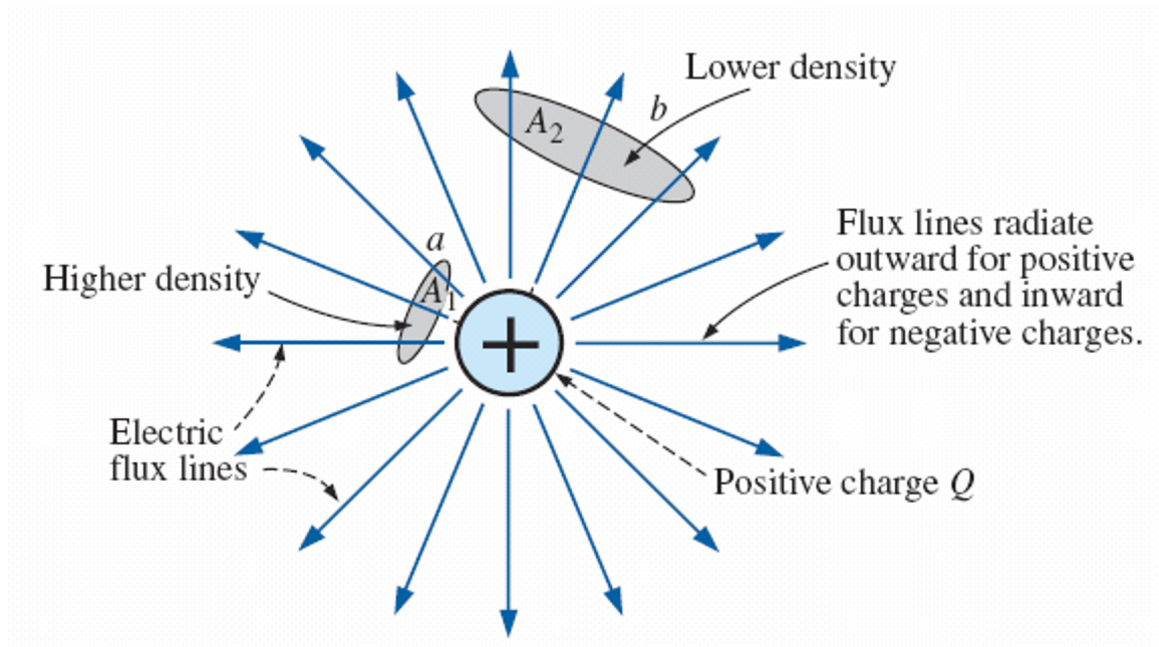


FIG. 10.1 *Flux distribution from an isolated positive charge.*

THE ELECTRIC FIELD

$$D = \frac{\psi}{A}$$

(flux/unit area)

$$\psi \equiv Q$$

(coulombs, C)

THE ELECTRIC FIELD

$$\mathcal{E} = \frac{F}{Q} \quad (\text{newtons/coulomb, N/C})$$

$$\mathcal{E} = \frac{kQ}{r^2} \quad (\text{N/C})$$

THE ELECTRIC FIELD

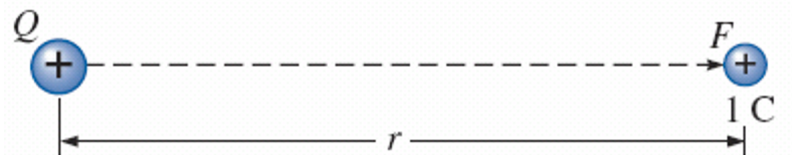


FIG. 10.2 *Determining the force on a unit charge r meters from a charge Q of similar polarity.*

THE ELECTRIC FIELD

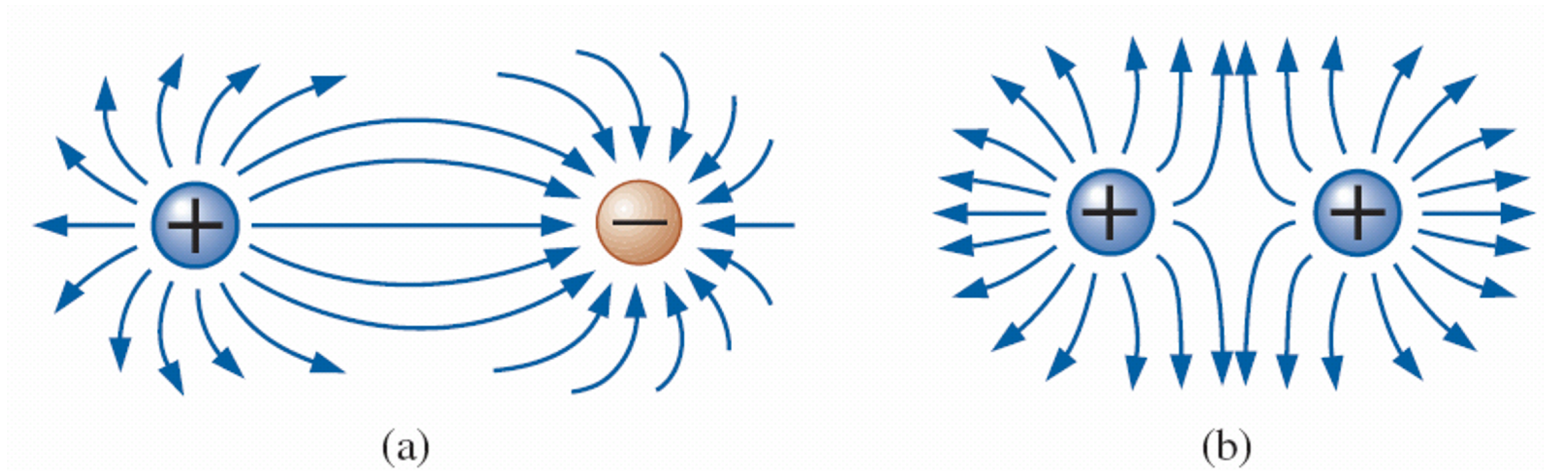


FIG. 10.3 *Electric flux distributions: (a) opposite charges; (b) like charges.*

THE ELECTRIC FIELD

- In general, electric flux lines always extend from a positively charged body to a negatively charged body, always extend or terminate perpendicular to the charged surfaces, and never intersect.

CAPACITANCE

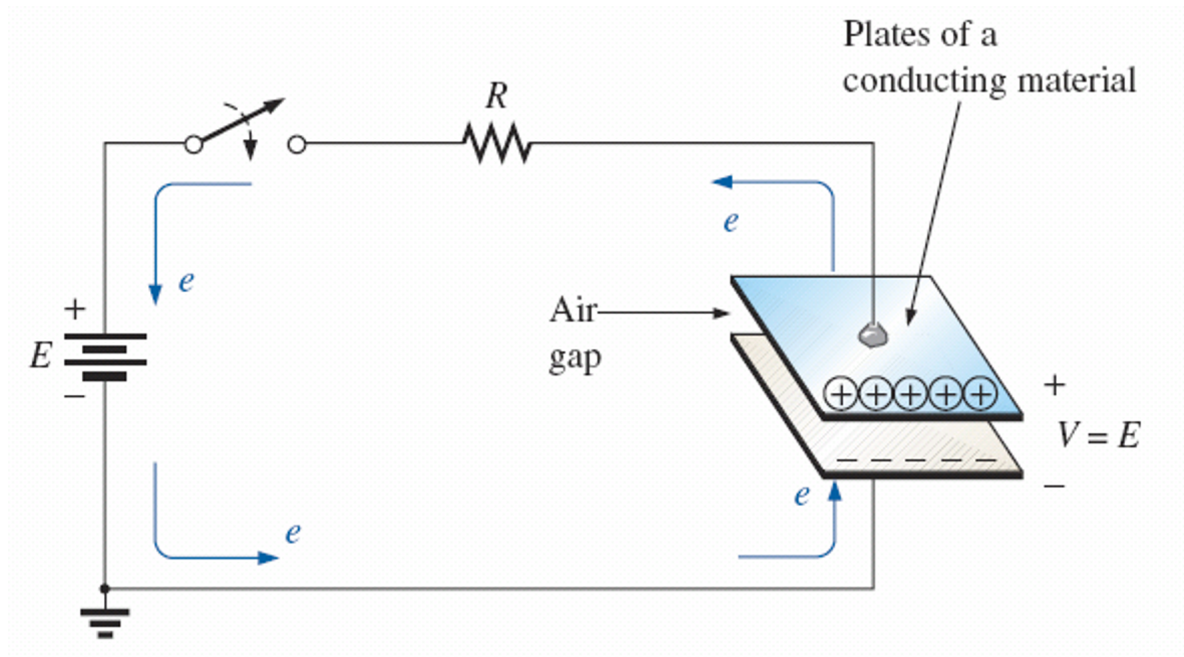


FIG. 10.4 *Fundamental charging circuit.*

CAPACITANCE

- Capacitance is a measure of a capacitor's ability to store charge on its plates—in other words, its storage capacity.
 - In addition, the higher the capacitance of a capacitor, the greater is the amount of charge stored on the plates for the same applied voltage.

CAPACITANCE

- Note the fringing that occurs at the edges as the flux lines originating from the points farthest away from the negative plate strive to complete the connection.

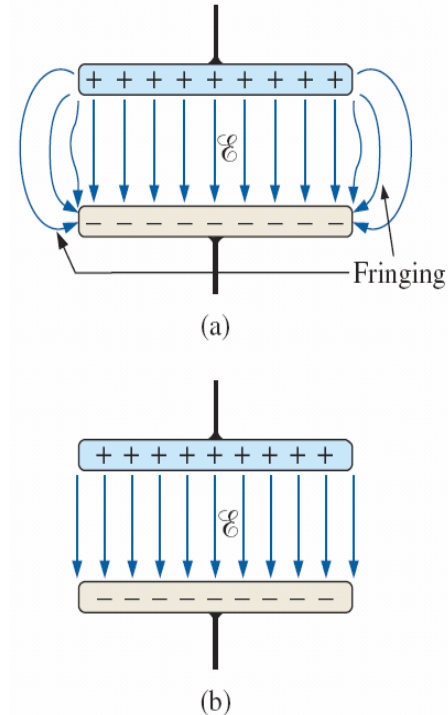


FIG. 10.6 *Electric flux distribution between the plates of a capacitor: (a) including fringing; (b) ideal.*

CAPACITANCE

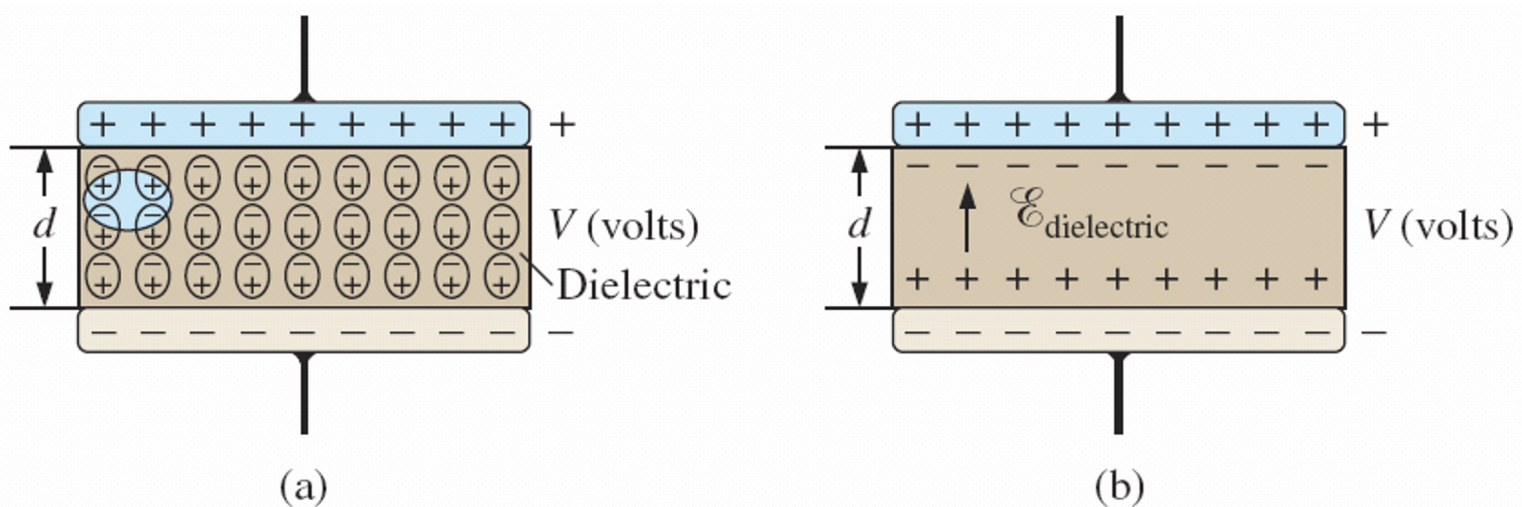


FIG. 10.7 *Effect of a dielectric on the field distribution between the plates of a capacitor: (a) alignment of dipoles in the dielectric; (b) electric field components between the plates of a capacitor with a dielectric present.*

CAPACITANCE

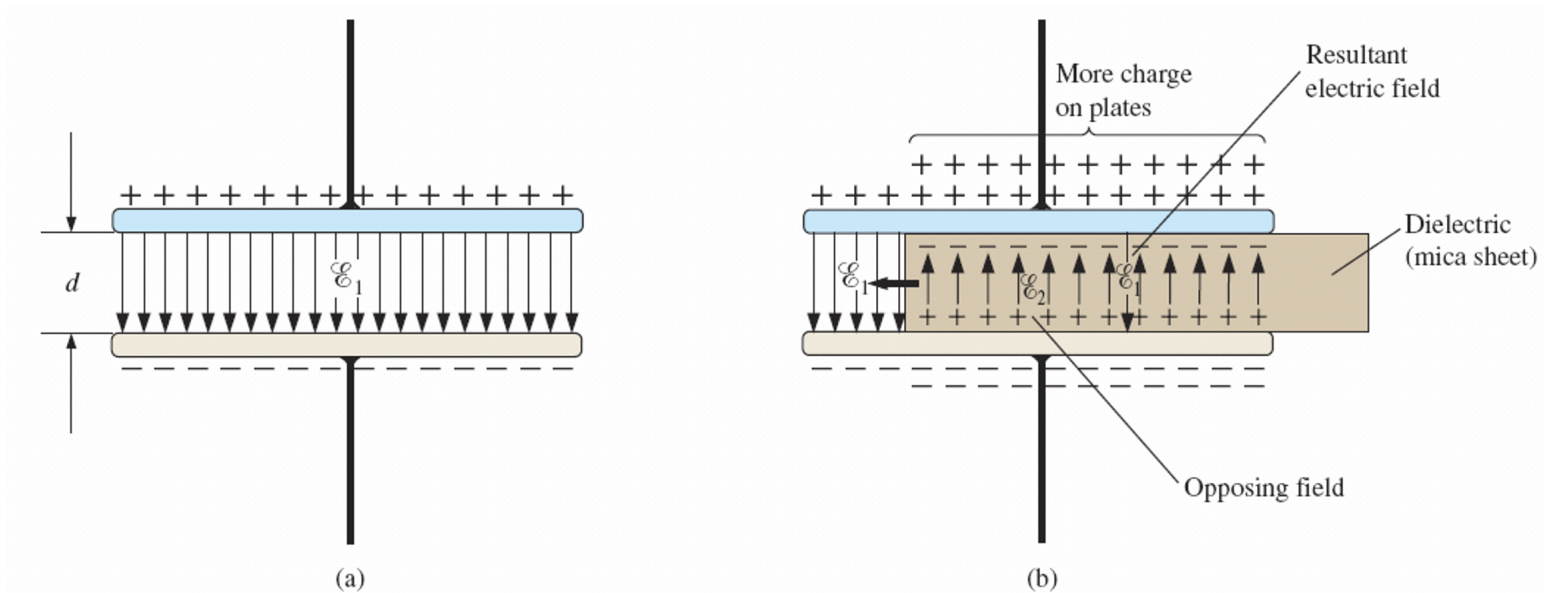


FIG. 10.8 *Demonstrating the effect of inserting a dielectric between the plates of a capacitor: (a) air capacitor; (b) dielectric being inserted.*

CAPACITORS

Capacitor Construction

- The basic components of a capacitor are: conductive plates, separation, and dielectric.
- Larger plates permit an increased area for the storage of charge, so the area of the plates should be in the numerator of the defining equation.

CAPACITORS

Capacitor Construction

- The smaller the distance between the plates, the larger is the capacitance, so this factor should appear in the numerator of the equation.
- Finally, since higher levels of permittivity result in higher levels of capacitance, the factor should appear in the numerator of the defining equation.

CAPACITORS

Capacitor Construction

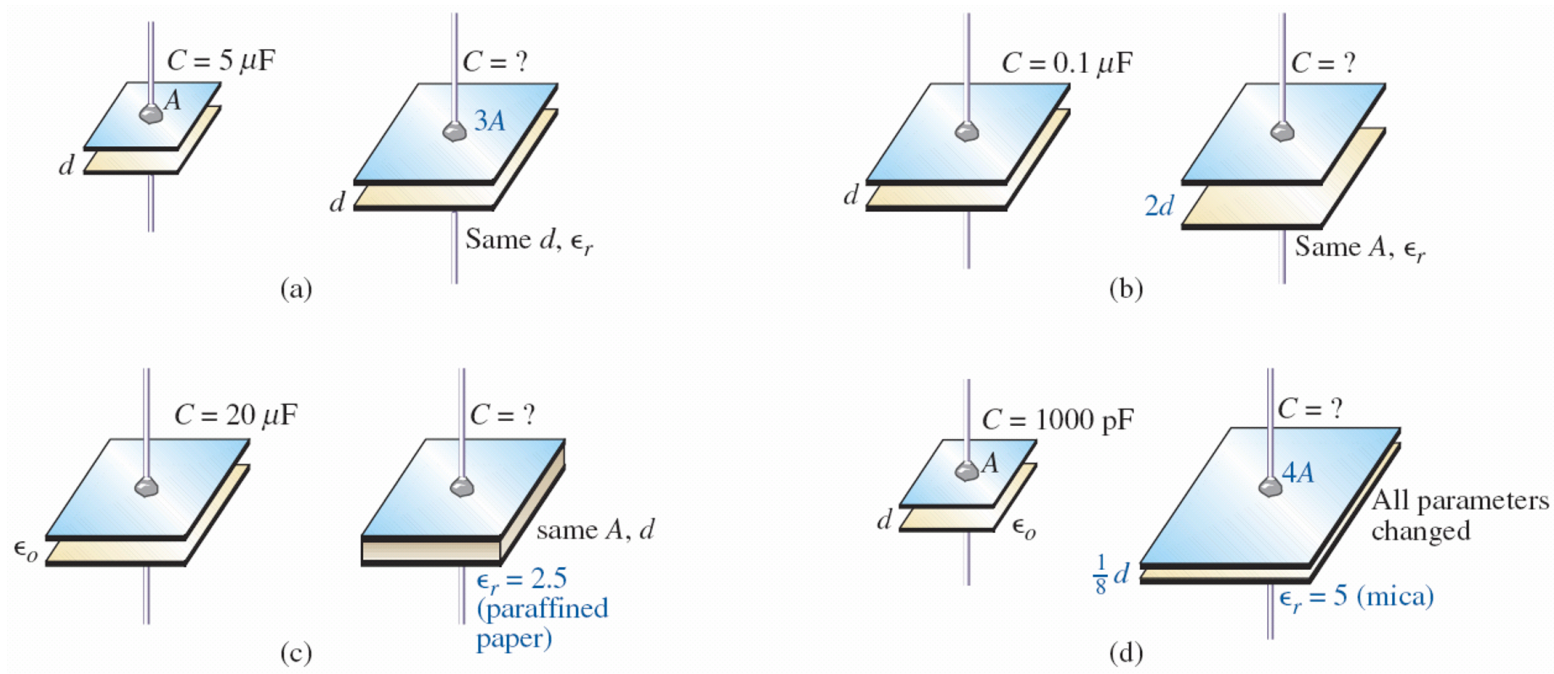


FIG. 10.9
Example 10.2.

CAPACITORS

Capacitor Construction

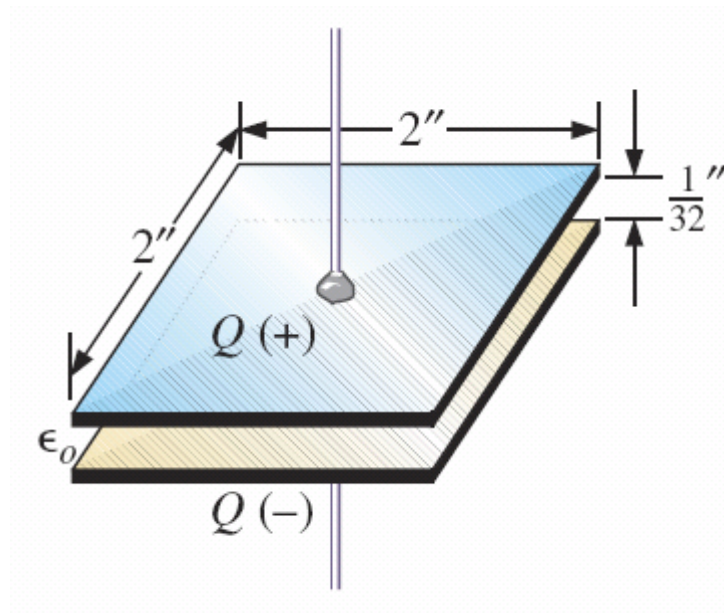


FIG. 10.10 *Air capacitor
for Example 10.3.*

CAPACITORS

Types of Capacitors

- Capacitors, like resistors, can be listed under two general headings: fixed and variable.
- The symbol for the fixed capacitor appears in Fig. 10.11(a).

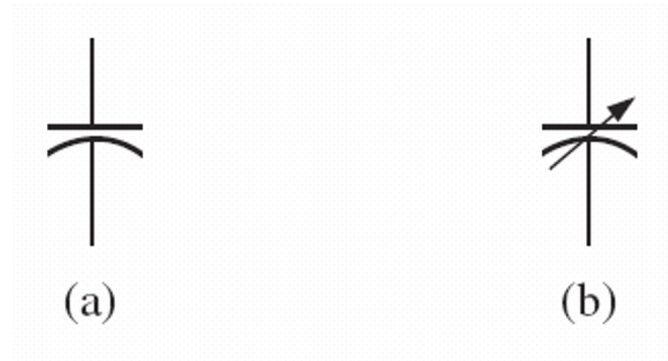


FIG. 10.11 Symbols for the capacitor: (a) fixed; (b) variable.

CAPACITORS

Types of Capacitors

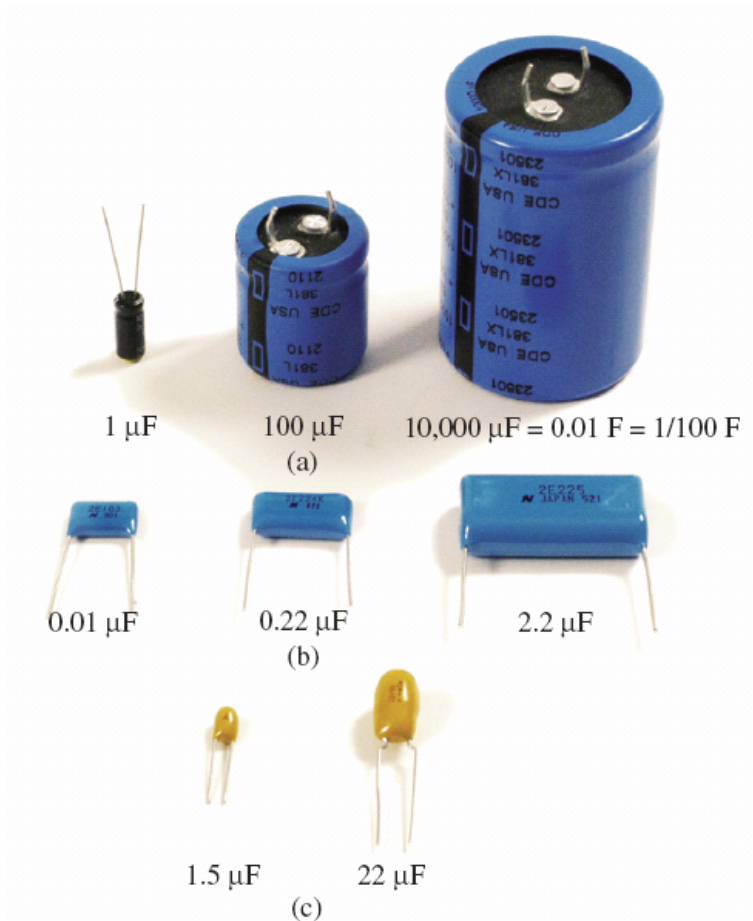
- Fixed Capacitors
 - Fixed-type capacitors come in all shapes and sizes.
 - However, in general, for the same type of construction and dielectric, the larger the required capacitance, the larger is the physical size of the capacitor.

CAPACITORS

Types of Capacitors

FIG. 10.12

Demonstrating that, in general, for each type of construction, the size of a capacitor increases with the capacitance value: (a) electrolytic; (b) polyester-film; (c) tantalum.



CAPACITORS

Types of Capacitors

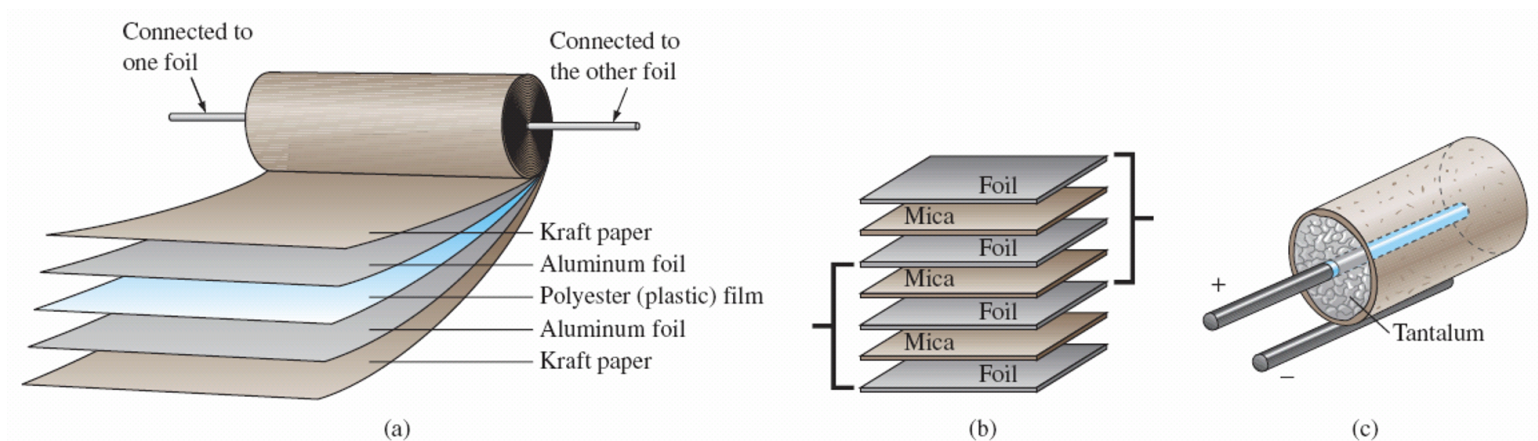


FIG. 10.13 *Three ways to increase the area of a capacitor: (a) rolling; (b) stacking; (c) insertion.*

CAPACITORS

Types of Capacitors

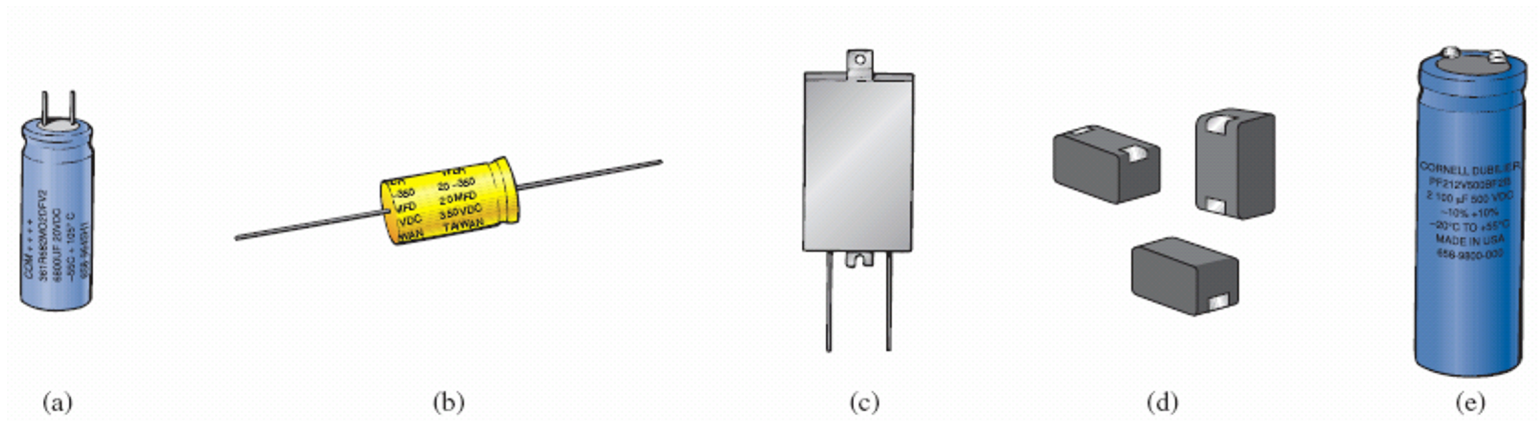


FIG. 10.14 Various types of electrolytic capacitors:
(a) miniature radial leads; (b) axial leads; (c)
flatpack; (d) surface-mount; (e) screw-in terminals.

CAPACITORS

Types of Capacitors

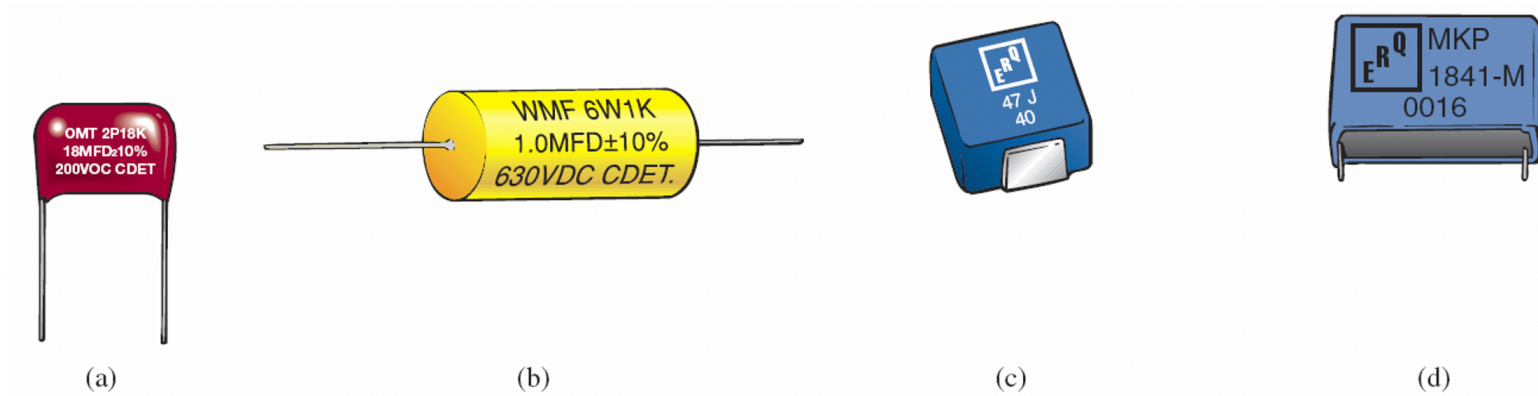


FIG. 10.15 (a) Film/foil polyester radial lead; (b) metalized polyester-film axial lead; (c) surface-mount polyester-film; (d) polypropylene-film, radial lead.

CAPACITORS

Types of Capacitors

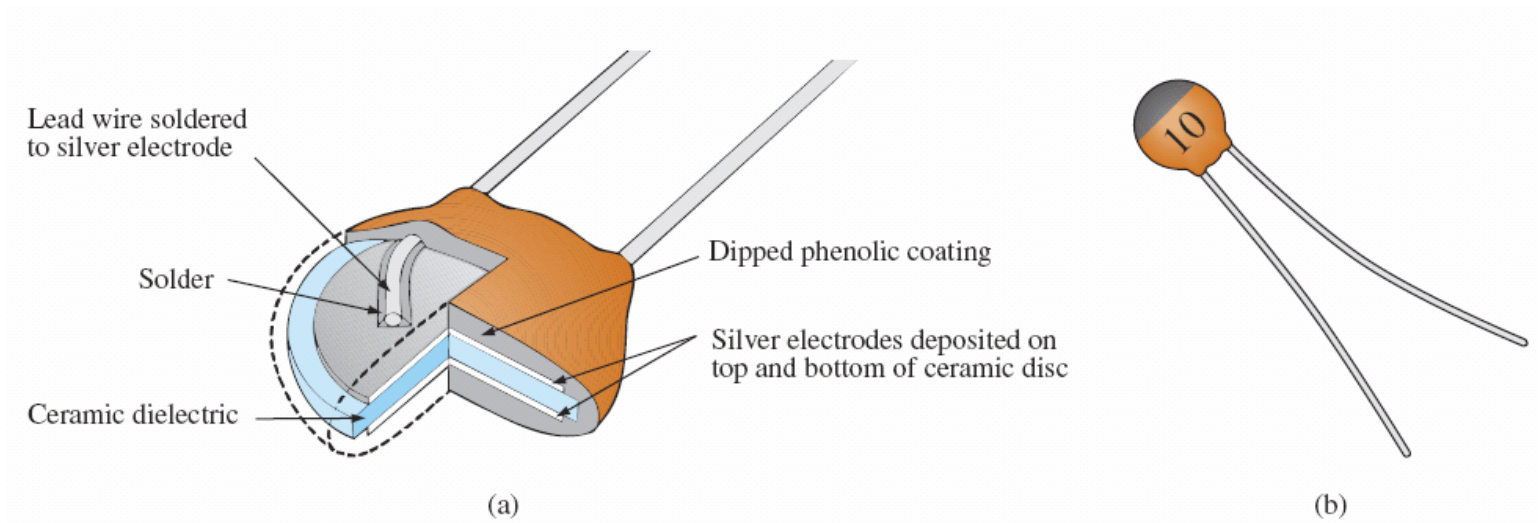


FIG. 10.16 *Ceramic (disc) capacitor: (a) construction; (b) appearance.*

CAPACITORS

Types of Capacitors

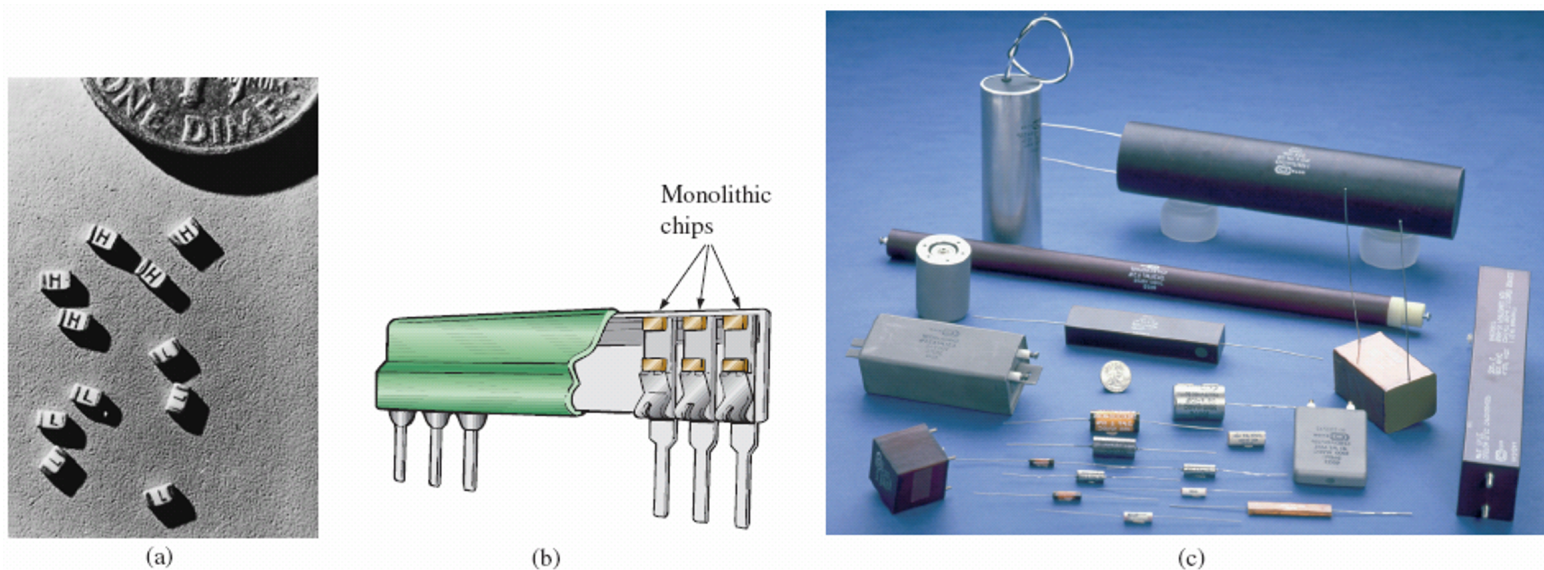


FIG. 10.17 *Mica capacitors: (a) and (b) surface-mount monolithic chips; (c) high-voltage/temperature mica paper capacitors. [(a) and (b) courtesy of Vishay Intertechnology, Inc.; (c) courtesy of Custom Electronics, Inc.]*

CAPACITORS

Types of Capacitors

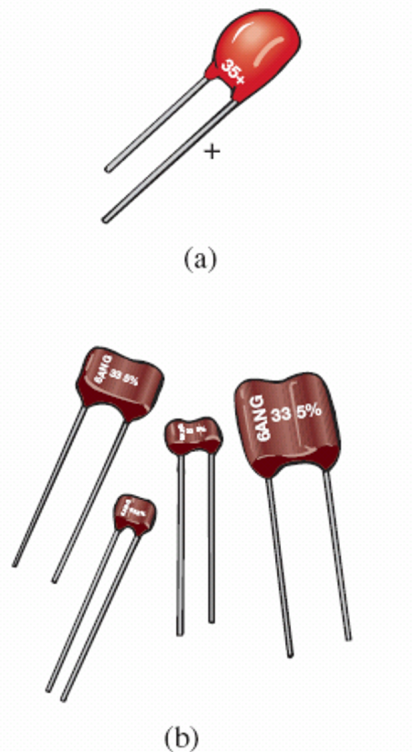


FIG. 10.18 *Dipped capacitors: (a) polarized tantalum; (b) nonpolarized mica.*



FIG. 10.19 *Oil-filled, metallic oval case snubber capacitor (the snubber removes unwanted voltage spikes).*

CAPACITORS

Types of Capacitors

- Variable Capacitors
 - All the parameters in Eq. (10.11) can be changed to some degree to create a variable capacitor.

CAPACITORS

Types of Capacitors

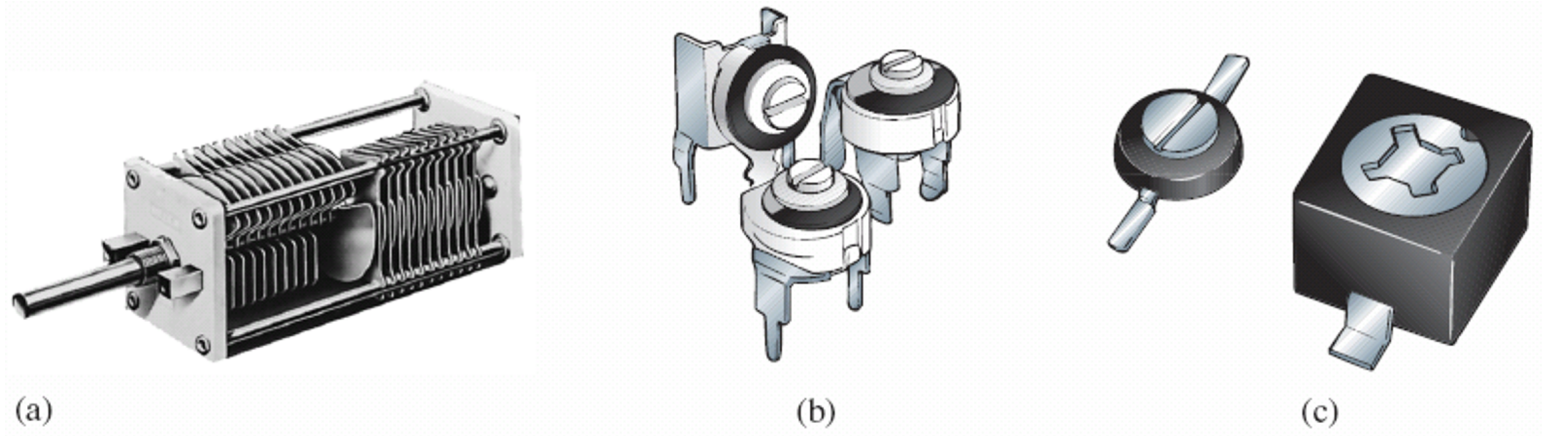


FIG. 10.20 *Variable capacitors: (a) air; (b) air trimmer; (c) ceramic dielectric compression trimmer. [(a) courtesy of James Millen Manufacturing Co.]*

CAPACITORS

Leakage Current and ESR

- Although we would like to think of capacitors as ideal elements, unfortunately, this is not the case.

CAPACITORS

Leakage Current and ESR

- Up to this point, we have assumed that the insulating characteristics of dielectrics prevent any flow of charge between the plates unless the breakdown voltage is exceeded.
- In reality, however, dielectrics are not perfect insulators, and they do carry a few free electrons in their atomic structure.

CAPACITORS

Leakage Current and ESR

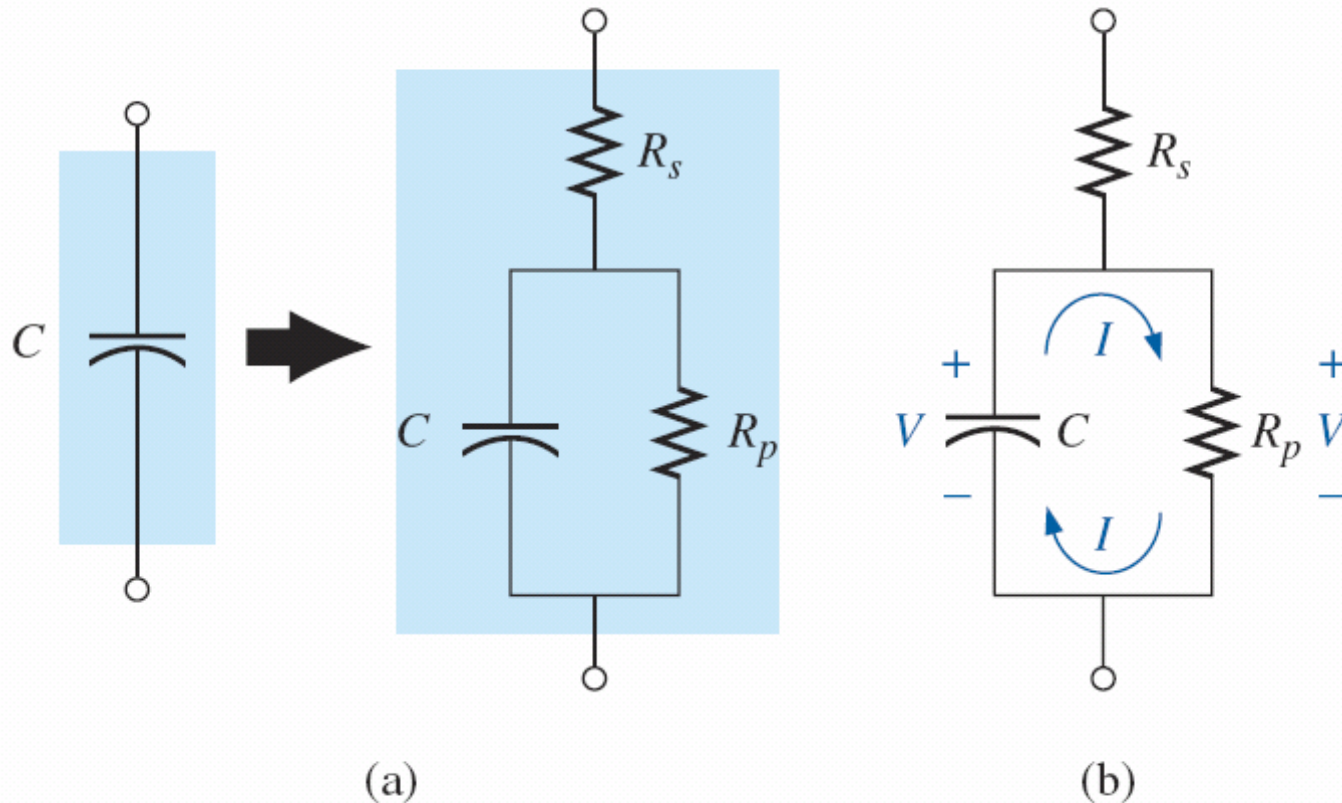


FIG. 10.21 Leakage current: (a) including the leakage resistance in the equivalent model for a capacitor; (b) internal discharge of a capacitor due to the leakage current.

CAPACITORS

Temperature Effects: ppm

- Every capacitor is temperature sensitive, with the nameplate capacitance level specified at room temperature.
- Depending on the type of dielectric, increasing or decreasing temperatures can cause either a drop or a rise in capacitance.

CAPACITORS

Temperature Effects: ppm

- If temperature is a concern for a particular application, the manufacturer will provide a temperature plot, such as shown in Fig. 10.22, or a ppm/°C (parts per million per degree Celsius) rating for the capacitor.

CAPACITORS

Temperature Effects: ppm

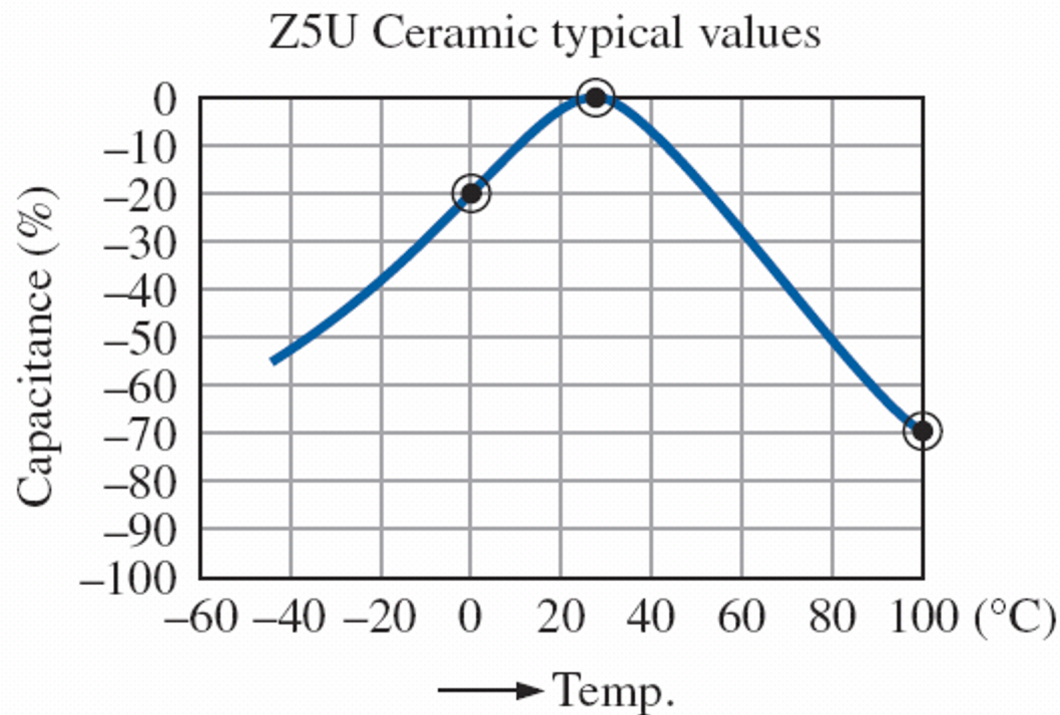


FIG. 10.22 *Variation of capacitor value with temperature.*

CAPACITORS

Capacitor Labeling

- Due to the small size of some capacitors, various marking schemes have been adopted to provide the capacitance level, tolerance, and, if possible, working voltage.
 - In general, however, as pointed out above, the size of the capacitor is the first indicator of its value.

CAPACITORS

Capacitor Labeling

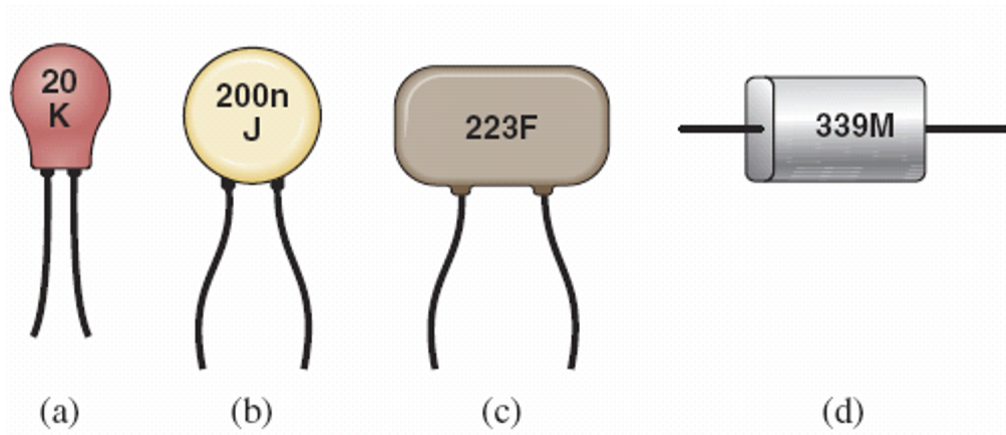


FIG. 10.23 *Various marking schemes for small capacitors.*

CAPACITORS: Measurement and Testing of Capacitors

- The capacitance of a capacitor can be read directly using a meter such as the Universal LCR Meter.

FIG. 10.24 *Digital reading capacitance meter. (Courtesy of B+K Precision.)*



CAPACITORS: Measurement and Testing of Capacitors

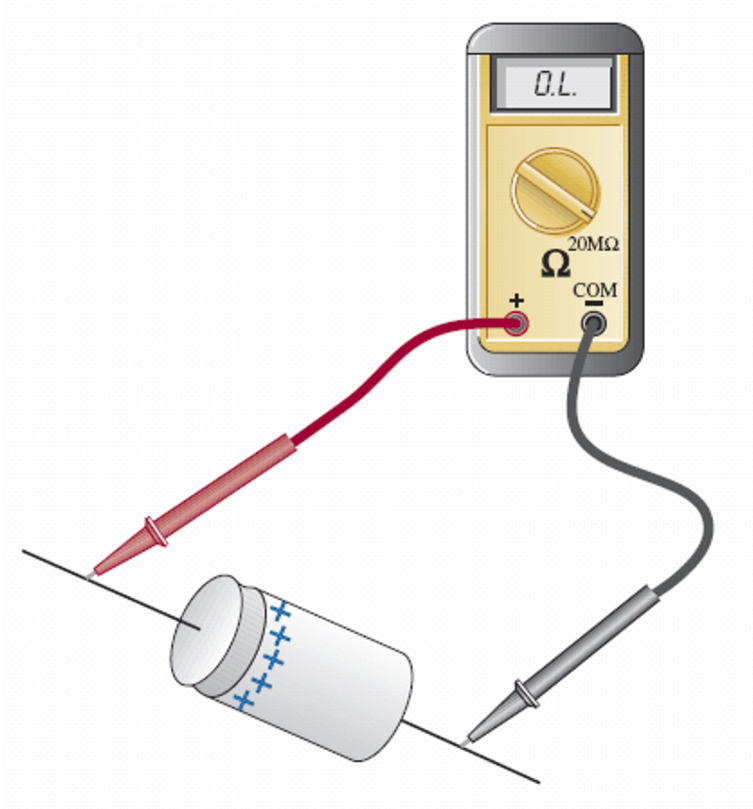


FIG. 10.25 *Checking the dielectric of an electrolytic capacitor.*

CAPACITORS

Standard Capacitor Values

- The most common capacitors use the same numerical multipliers encountered for resistors.
 - The vast majority are available with 5%, 10%, or 20% tolerances.
 - There are capacitors available, however, with tolerances of 1%, 2%, or 3%, if you are willing to pay the price.

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

- The placement of charge on the plates of a capacitor does not occur instantaneously.
- Instead, it occurs over a period of time determined by the components of the network.

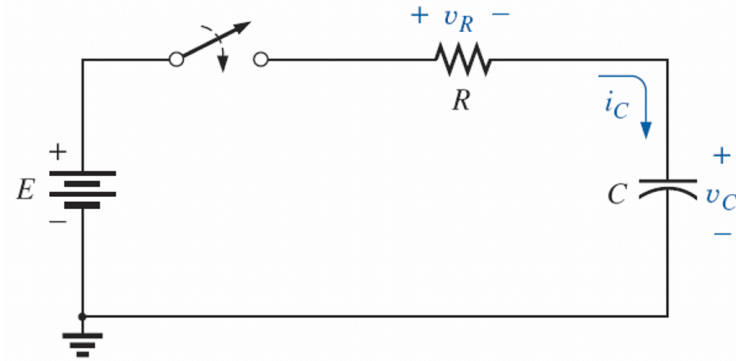


FIG. 10.26 *Basic R-C charging network.*

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

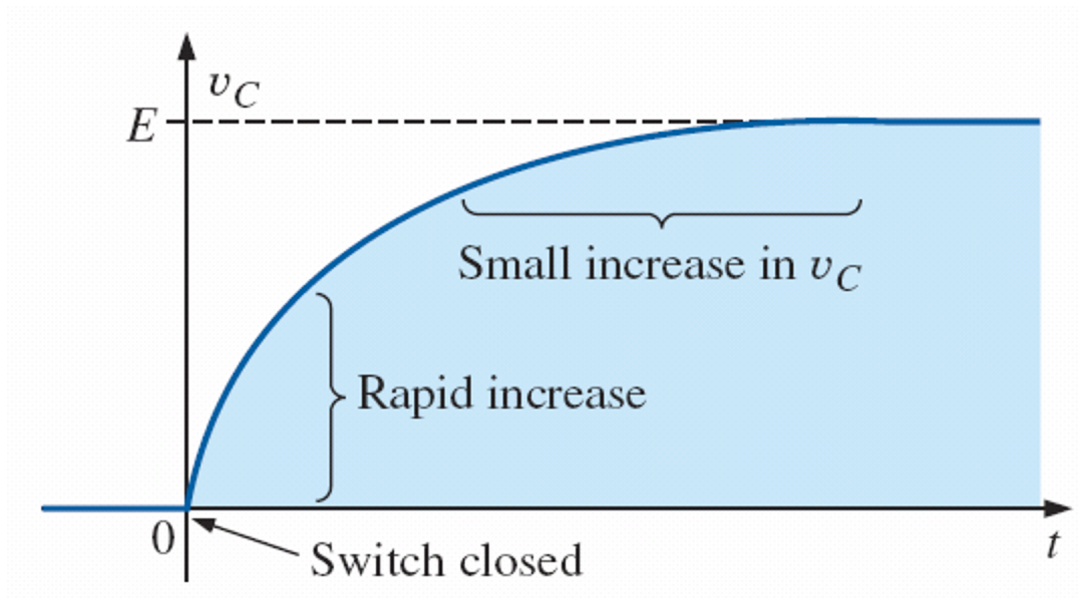


FIG. 10.27 v_C during the charging phase.

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

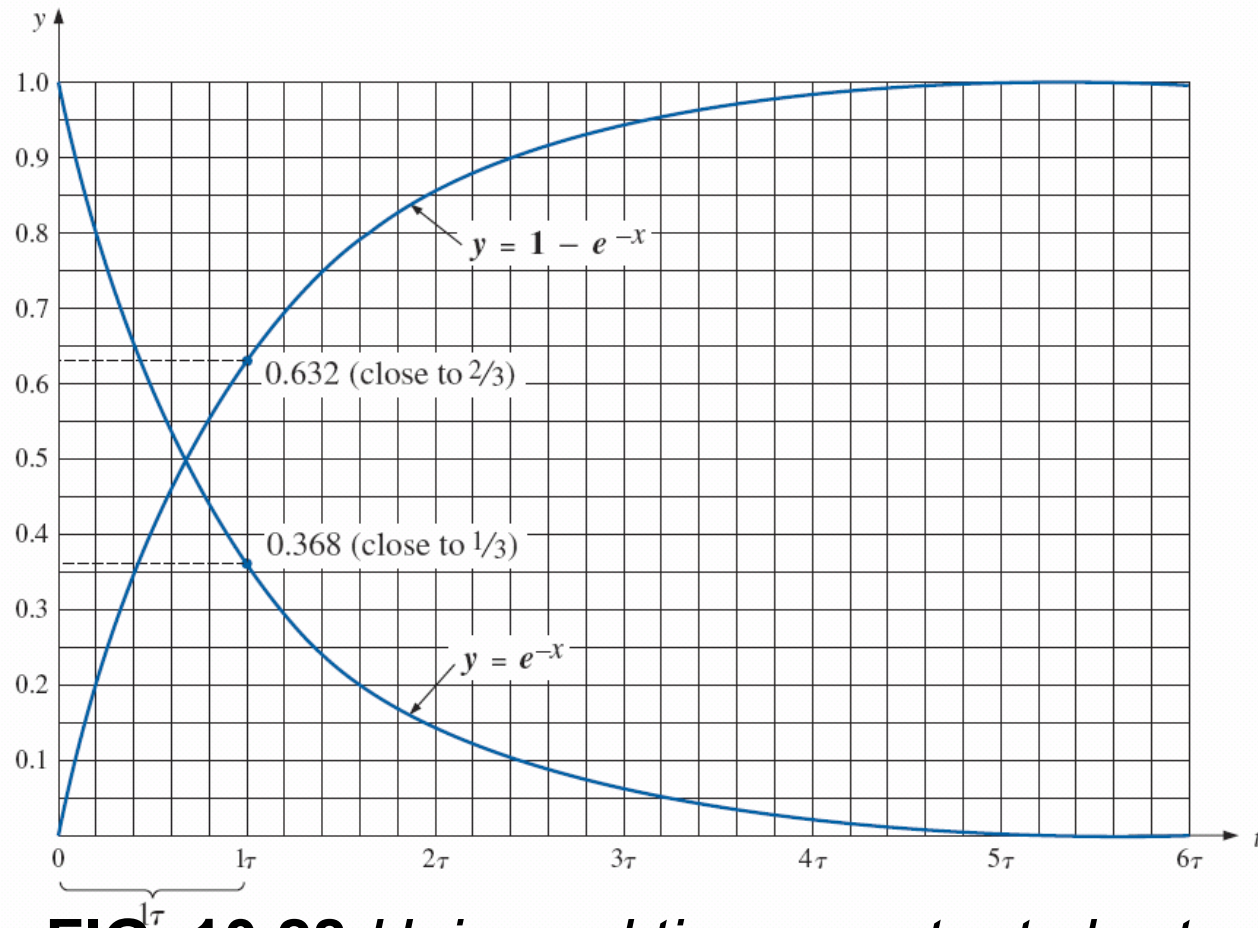


FIG. 10.28 *Universal time constant chart.*

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

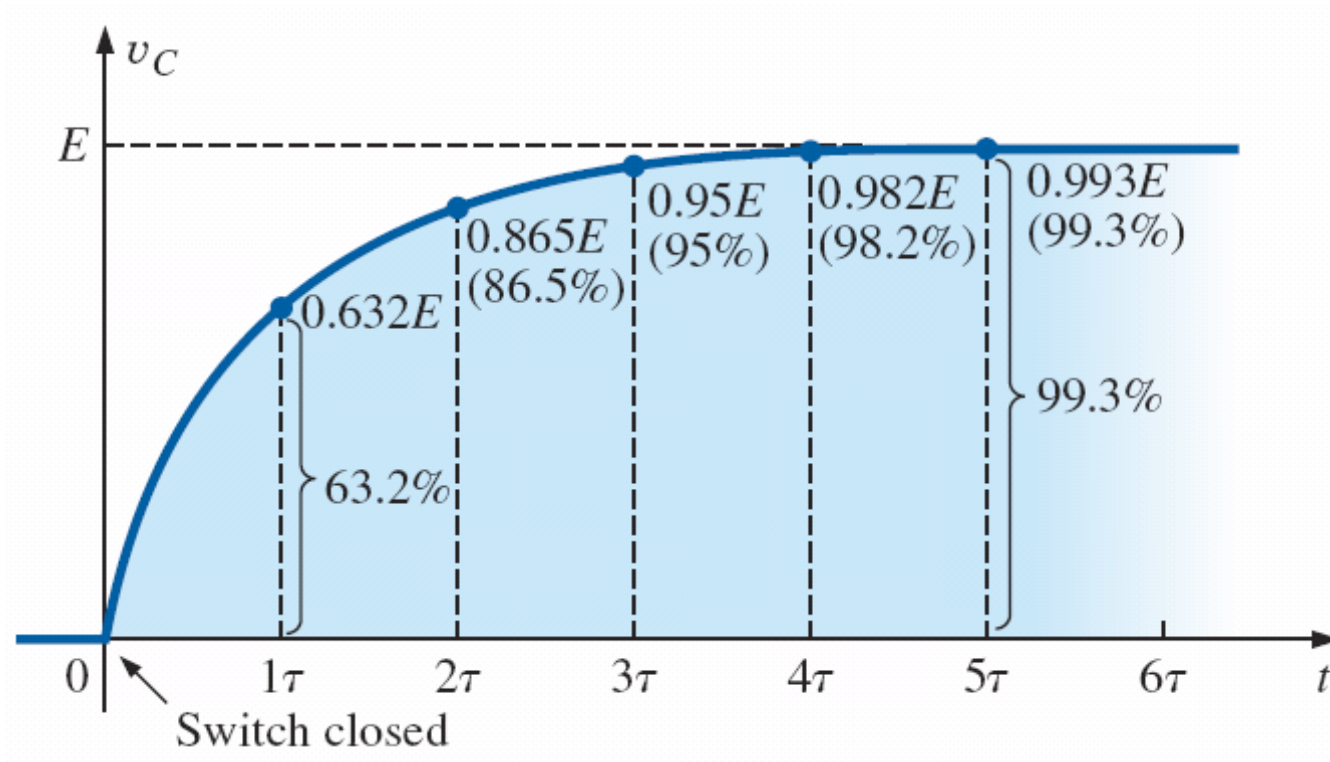


FIG. 10.29 Plotting the equation $y_C = E(1 - e^{-t/\tau})$ versus time (t).

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

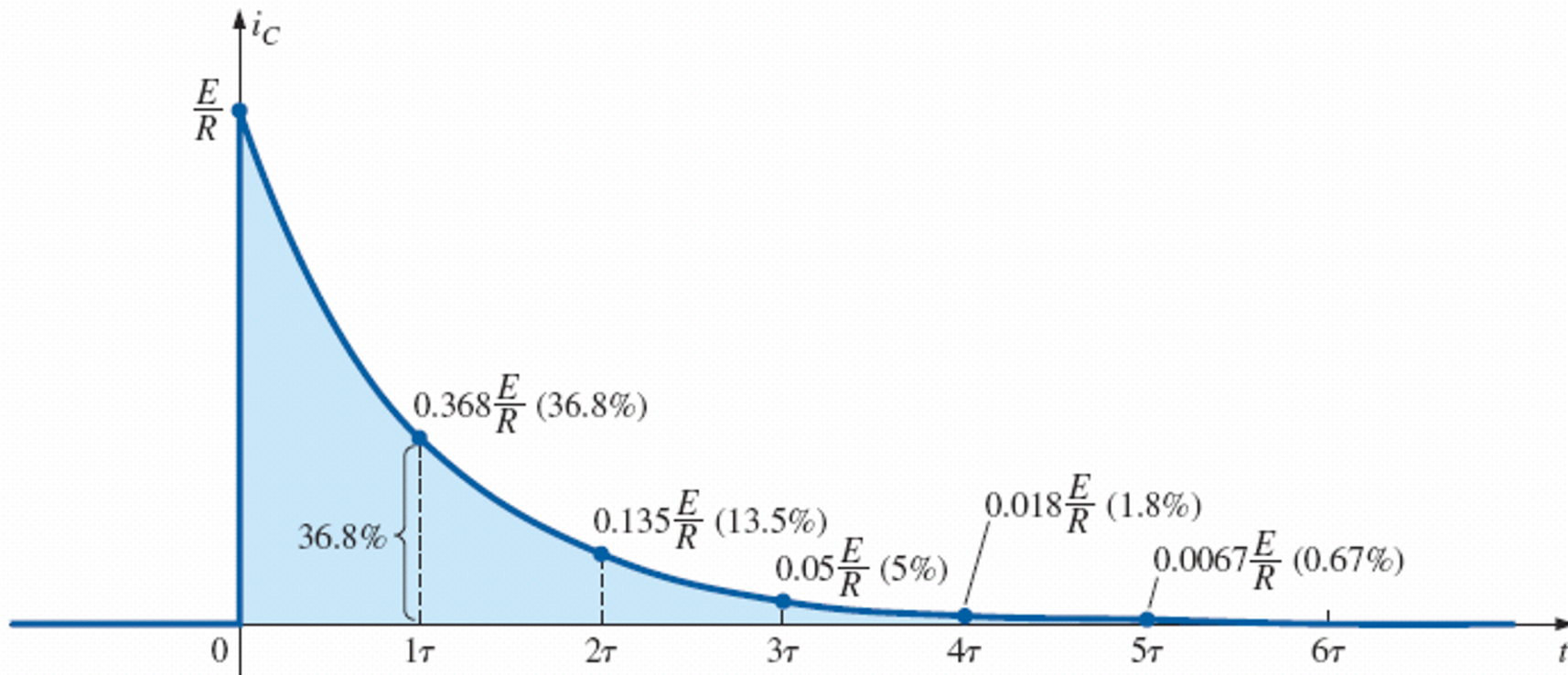


FIG. 10.30

Plotting the equation $i_C = \frac{E}{R}e^{-t/\tau}$ versus time (t).

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

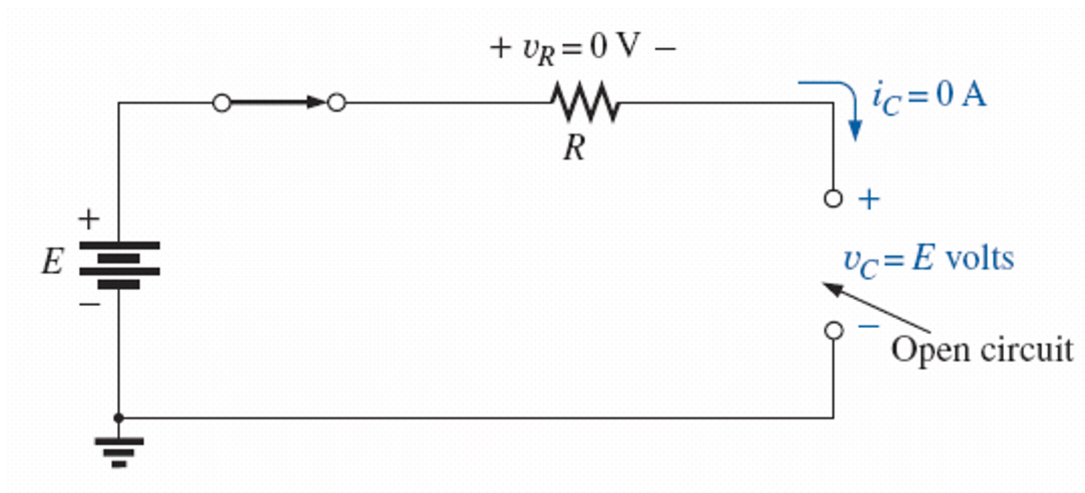


FIG. 10.31 *Demonstrating that a capacitor has the characteristics of an open circuit after the charging phase has passed.*

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

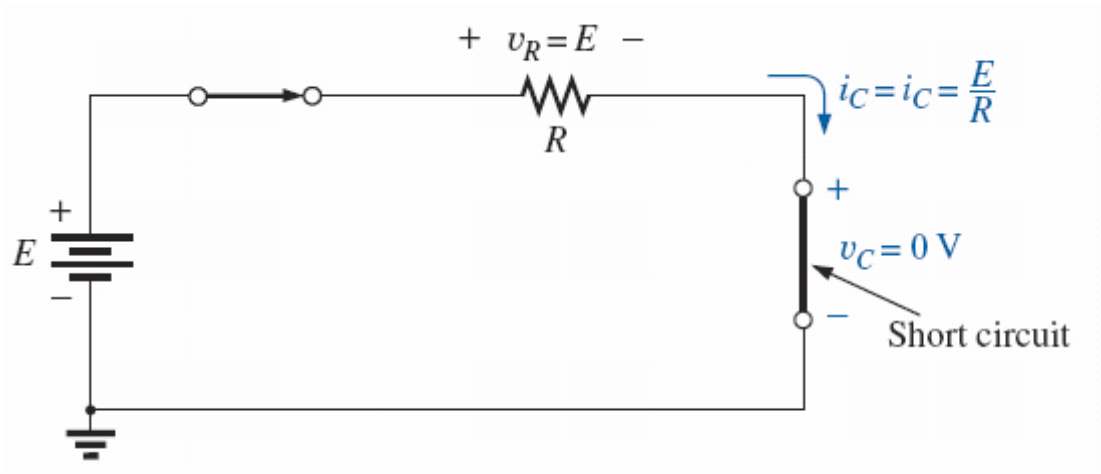


FIG. 10.32 *Revealing the short-circuit equivalent for the capacitor that occurs when the switch is first closed.*

TRANSIENTS IN CAPACITIVE NETWORKS: The Charging Phase

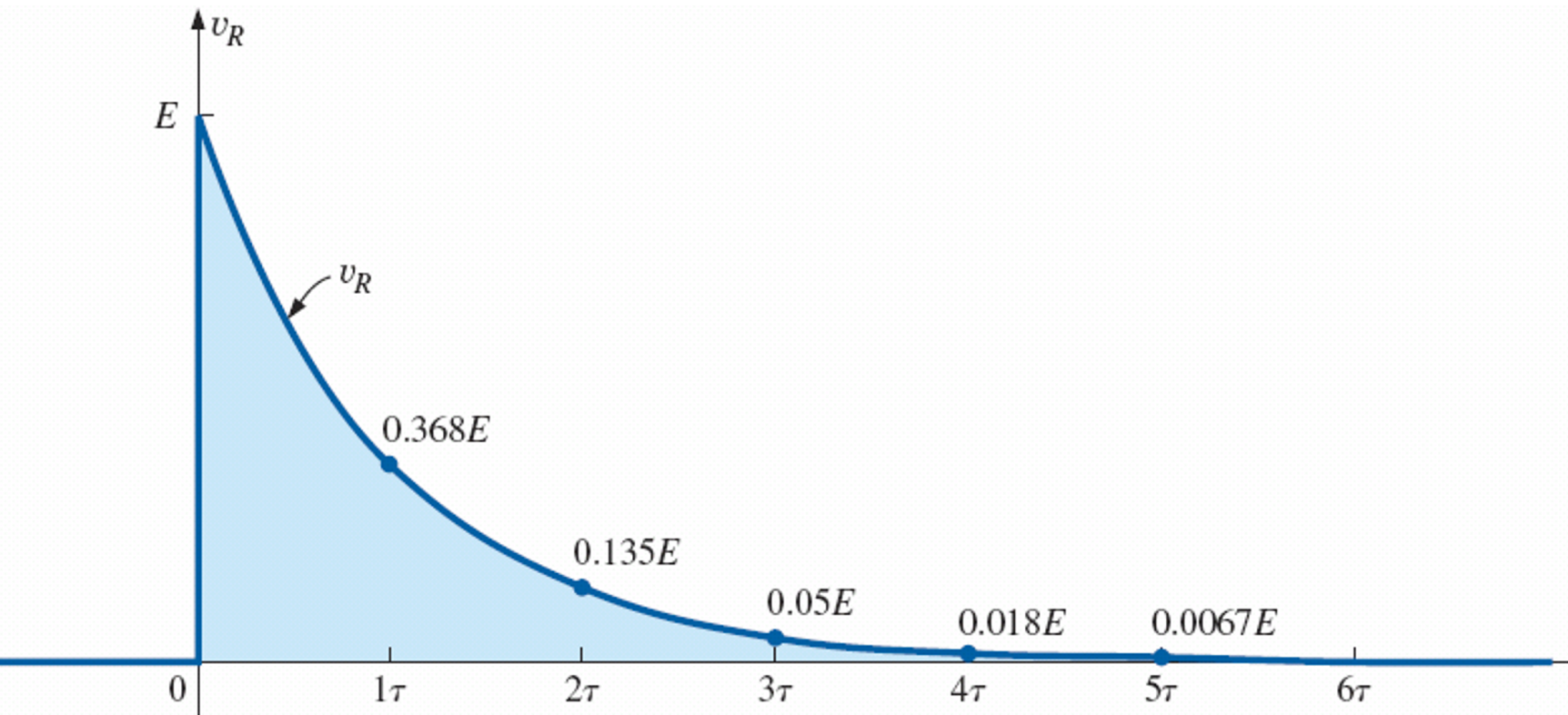


FIG. 10.33

Plotting the equation $v_R = Ee^{-t/\tau}$ versus time (t).

Using the Calculator to Solve Exponential Functions

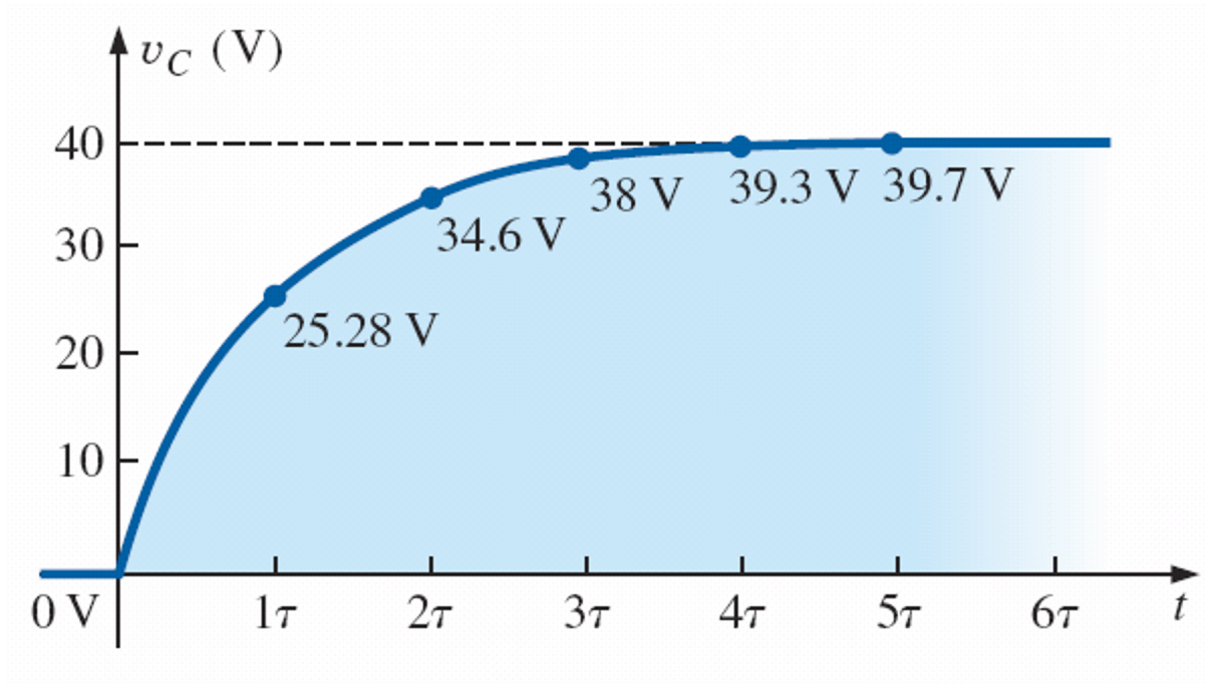


FIG. 10.37 v_C versus time for the charging network in Fig. 10.36.

Using the Calculator to Solve Exponential Functions

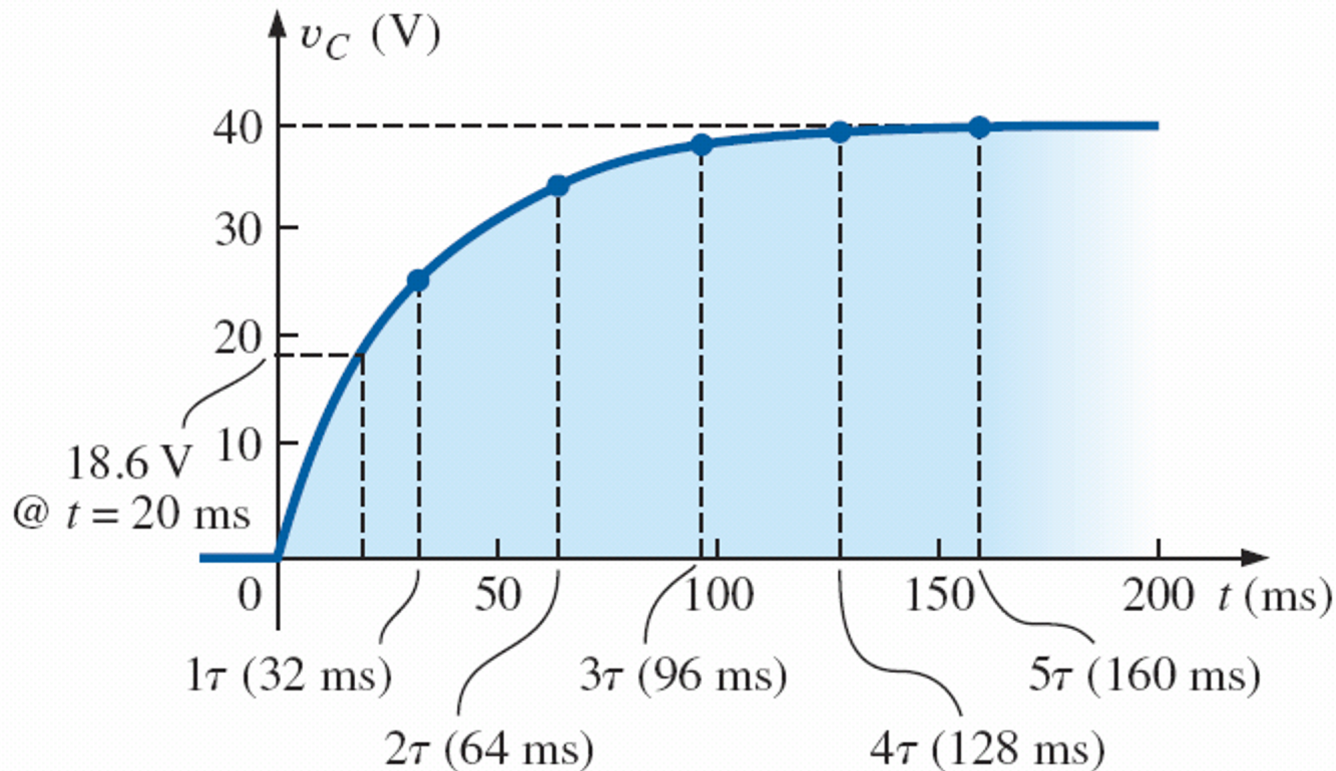


FIG. 10.38 *Plotting the waveform in Fig. 10.37 versus time (t).*

Using the Calculator to Solve Exponential Functions

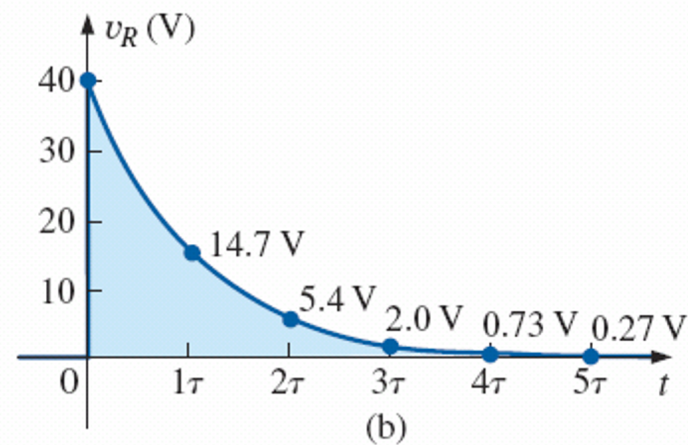
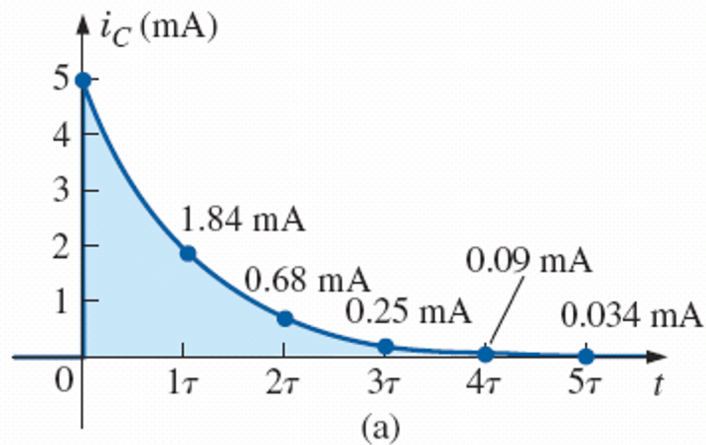


FIG. 10.39 i_C and v_R for the charging network in Fig. 10.37.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

- We now investigate how to discharge a capacitor while exerting some control on how long the discharge time will be.
- You can, of course, place a lead directly across a capacitor to discharge it very quickly—and possibly cause a visible spark.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

- For larger capacitors such those in TV sets, this procedure should not be attempted because of the high voltages involved—unless, of course, you are trained in the maneuver.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

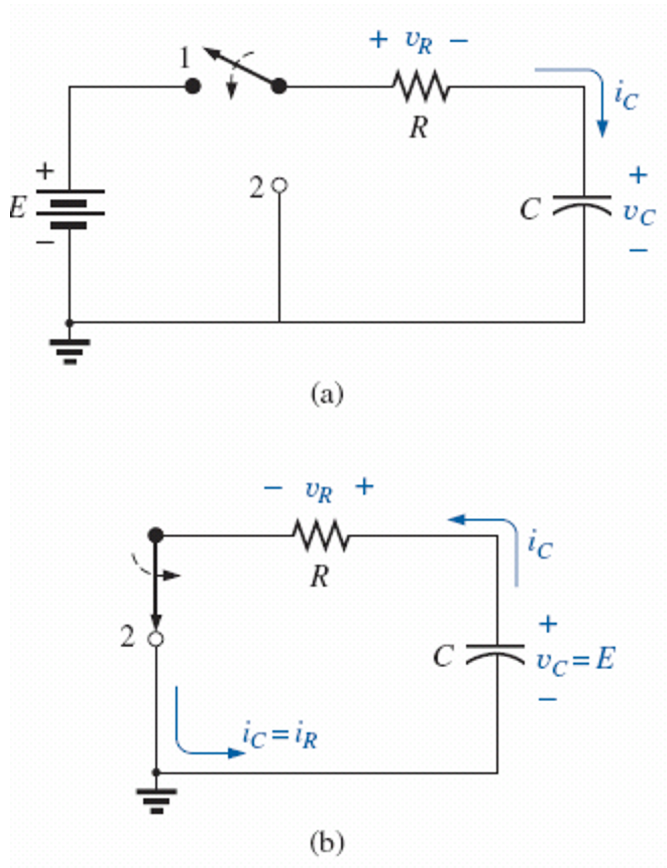


FIG. 10.40 (a) Charging network; (b) discharging configuration.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

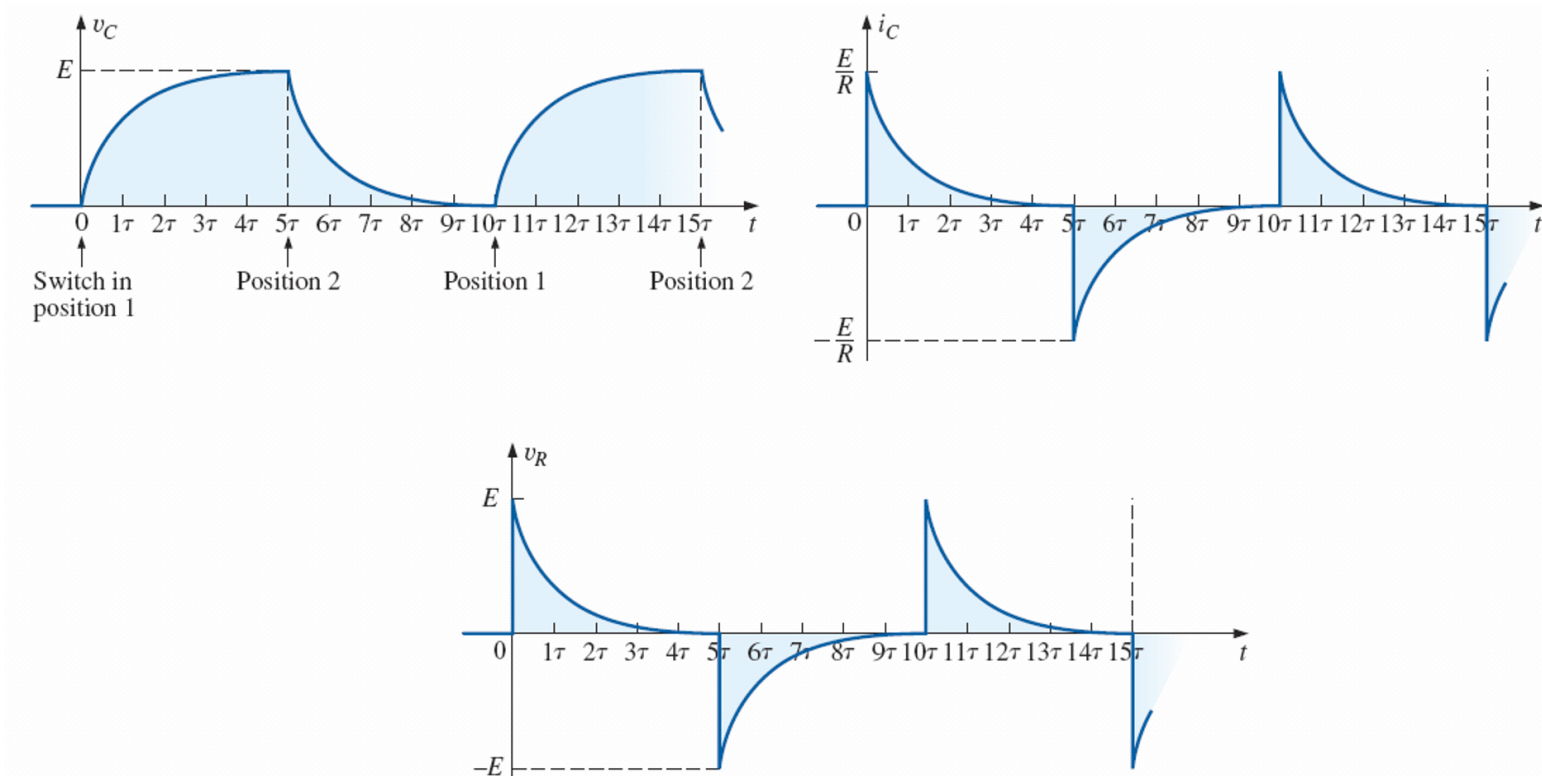


FIG. 10.41 v_C , i_C , and v_R for 5τ switching between contacts in Fig. 10.40(a).

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

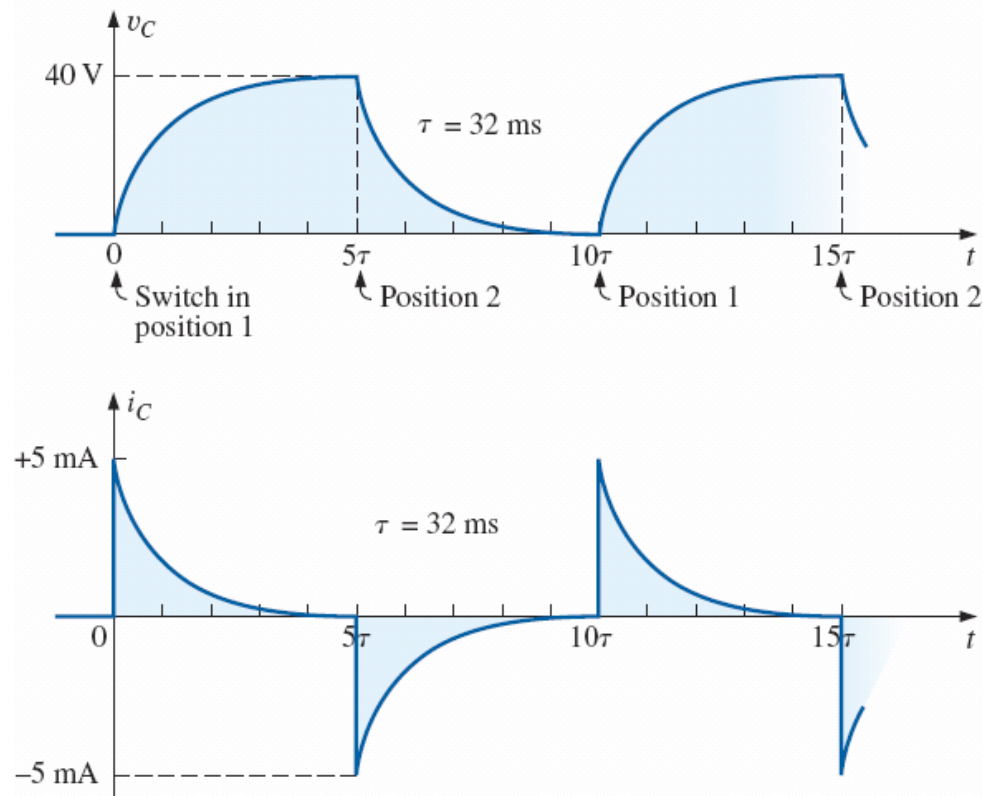


FIG. 10.42 v_C and i_C for the network in Fig. 10.39(a) with the values in Example 10.6.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

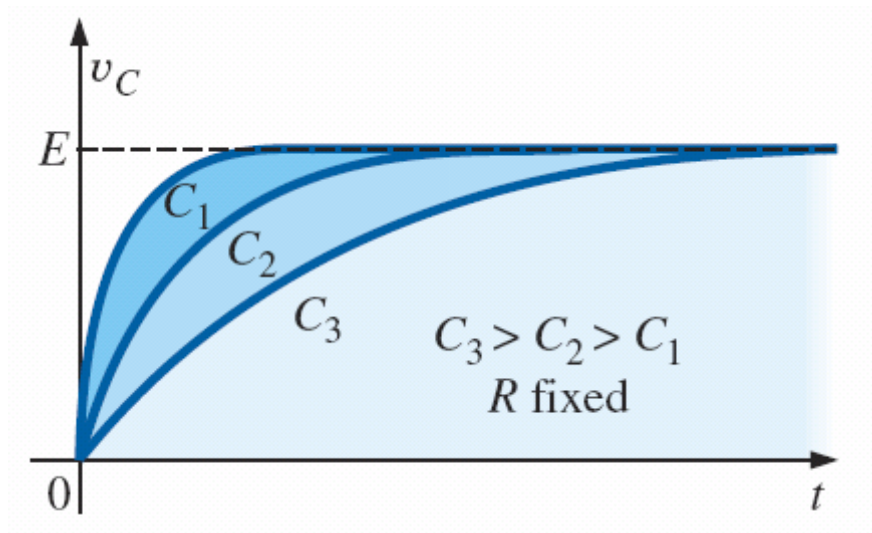


FIG. 10.44 *Effect of increasing values of C (with R constant) on the charging curve for v_C .*

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

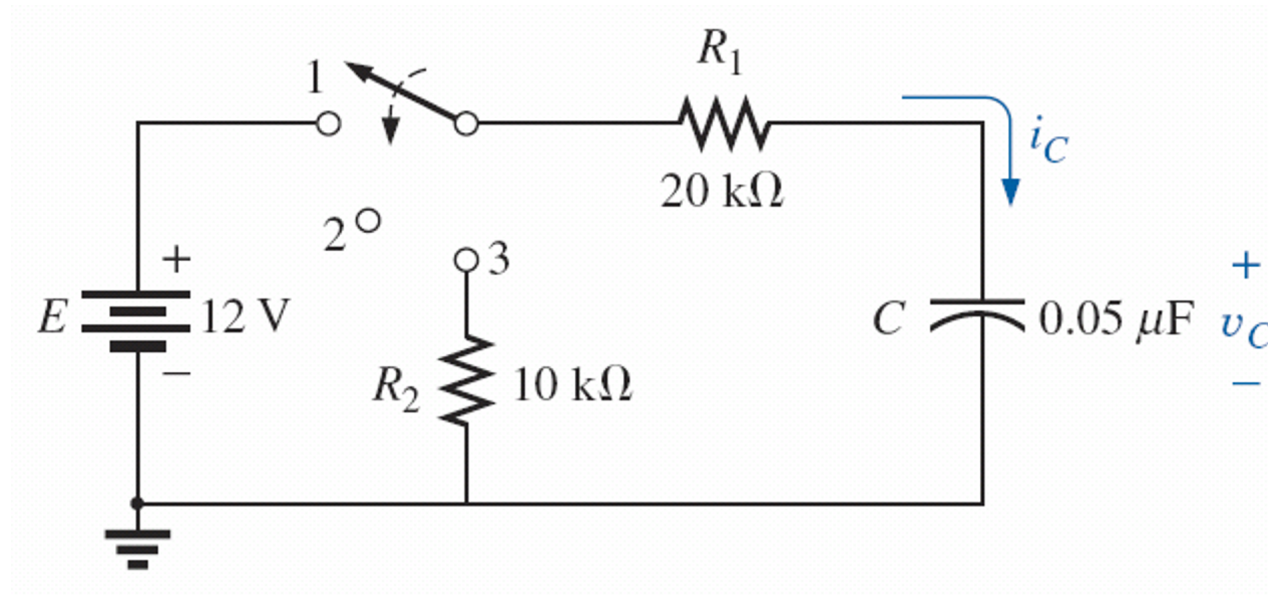


FIG. 10.45 *Network to be analyzed in Example 10.8.*

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

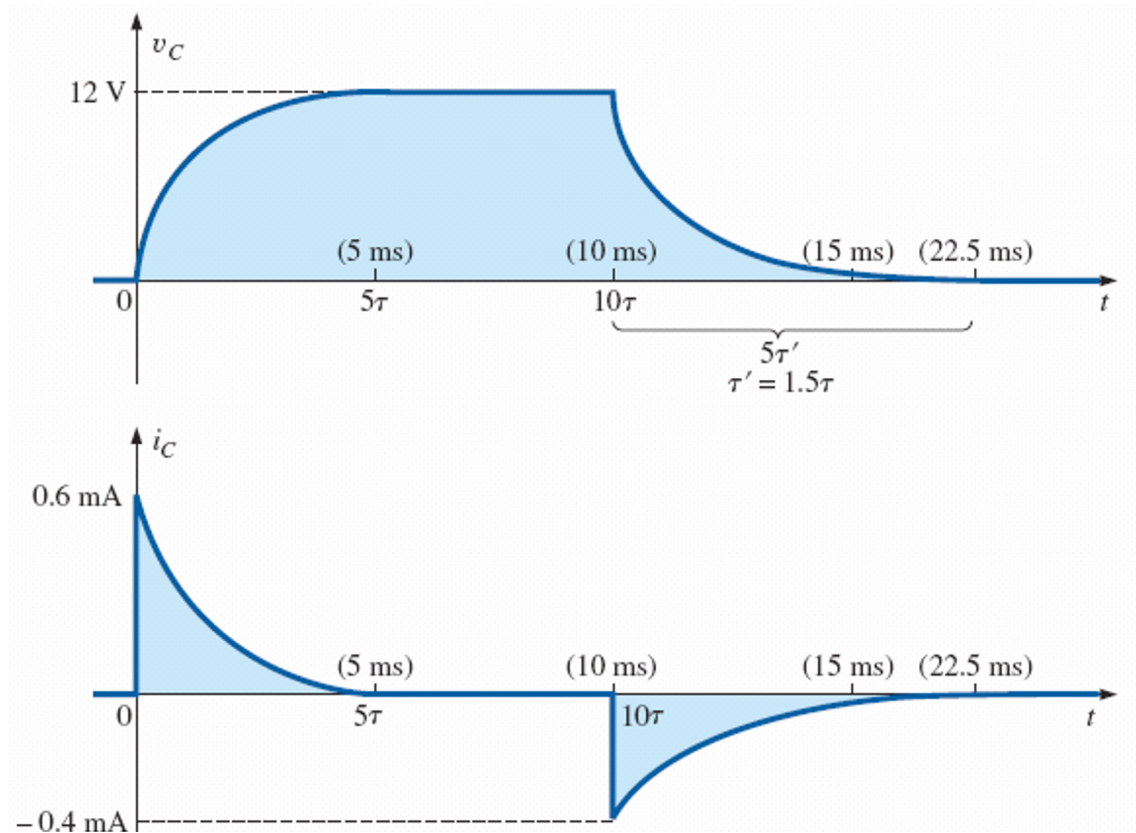


FIG. 10.46 v_C and i_C for the network in Fig. 10.45.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

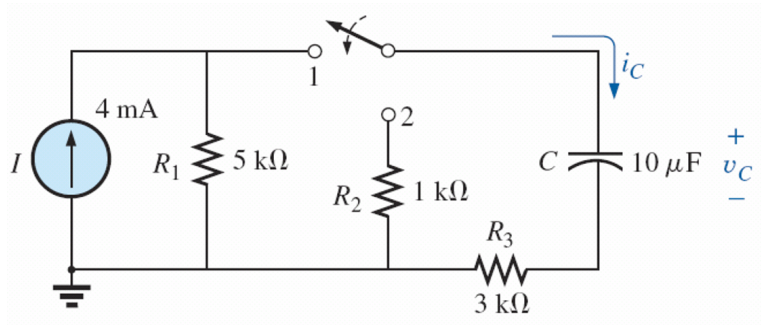


FIG. 10.47 Network to be analyzed in Example 10.9.

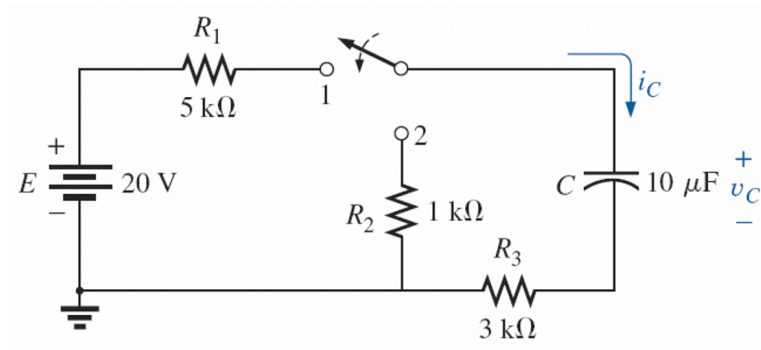


FIG. 10.48 The charging phase for the network in Fig. 10.47.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

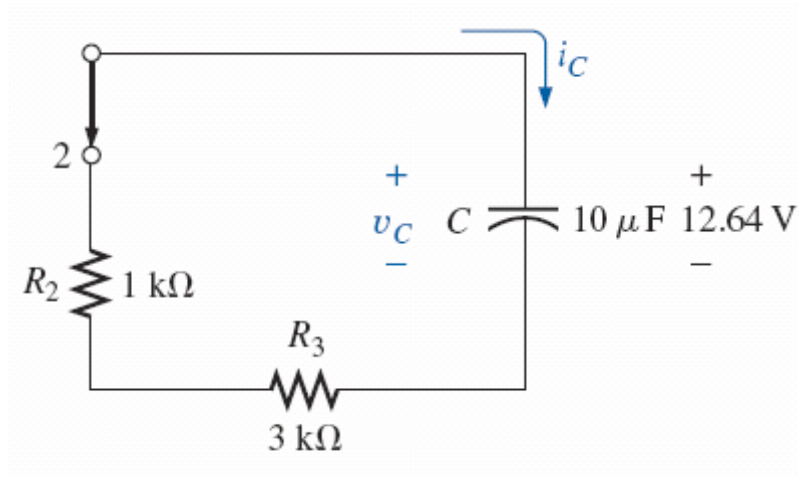


FIG. 10.49 Network in Fig. 10.48 when the switch is moved to position 2 at $t = 1t_1$.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

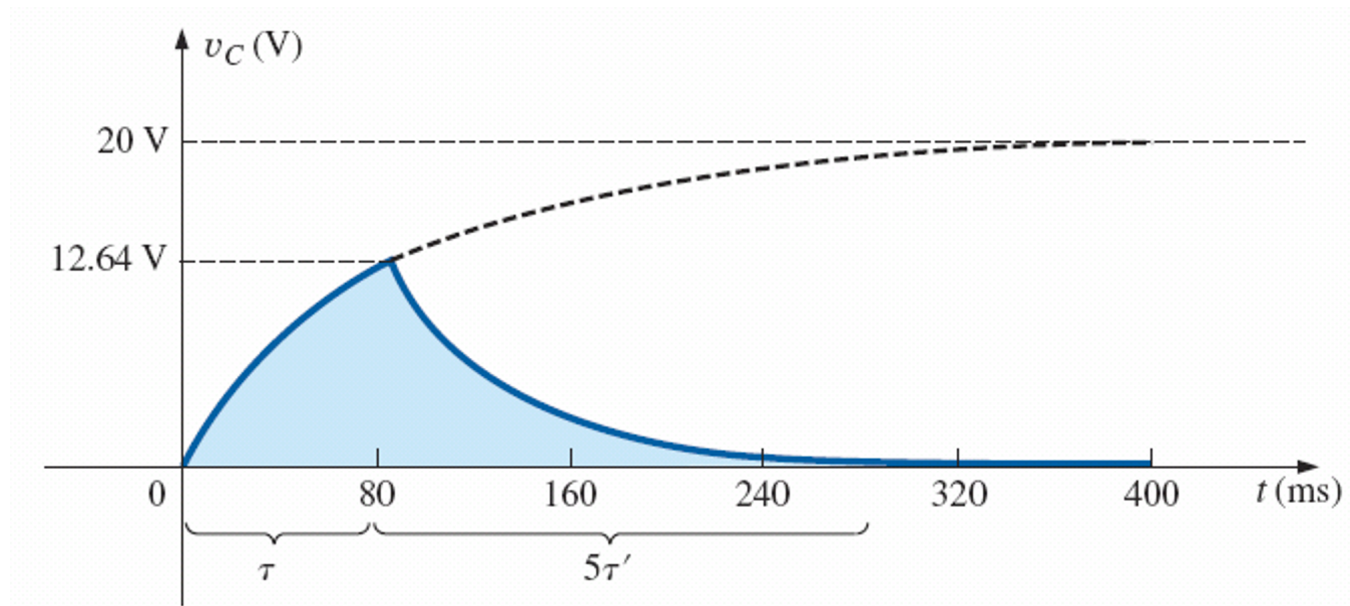


FIG. 10.50 v_C for the network in Fig. 10.48.

TRANSIENTS IN CAPACITIVE NETWORKS: Discharging Phase

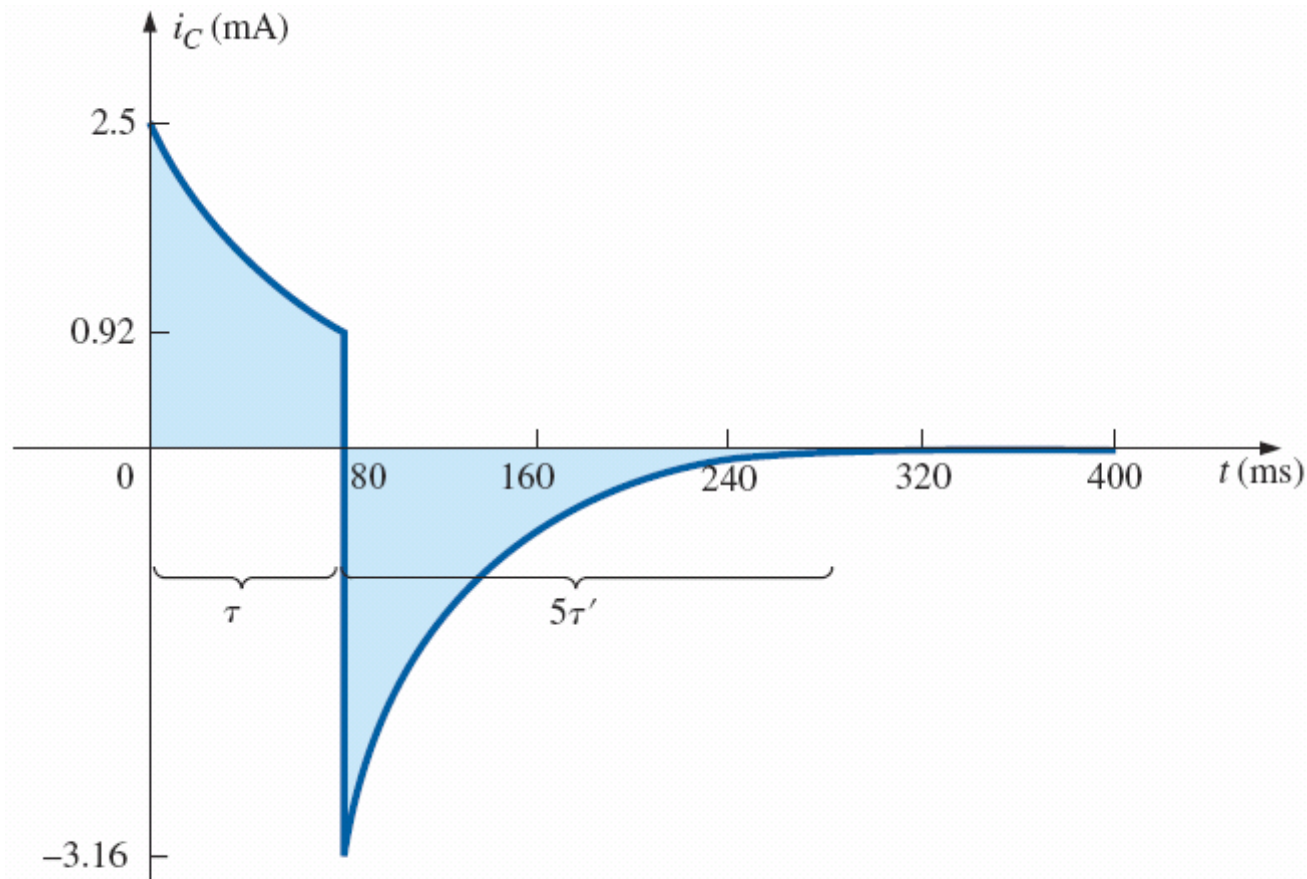


FIG. 10.51 i_C for the network in Fig. 10.48.

INITIAL CONDITIONS

- The voltage across the capacitor at this instant is called the initial value

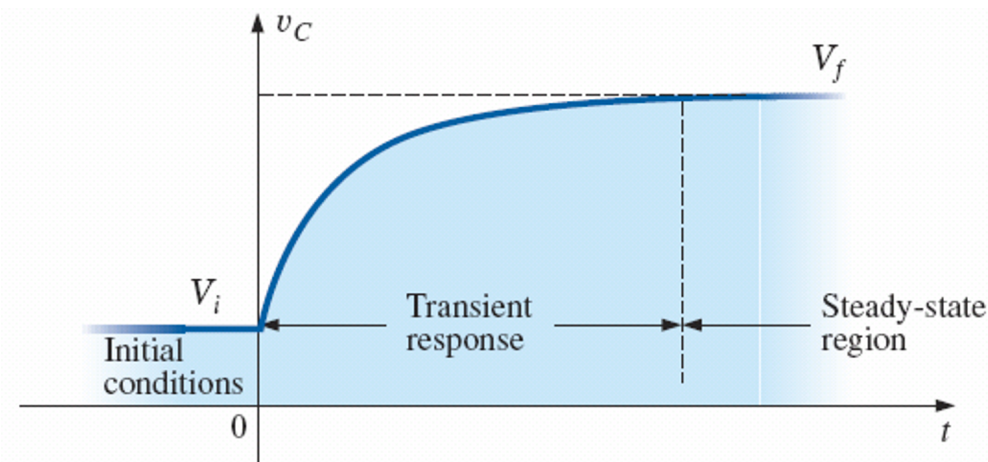


FIG. 10.52 *Defining the regions associated with a transient response.*

INITIAL CONDITIONS

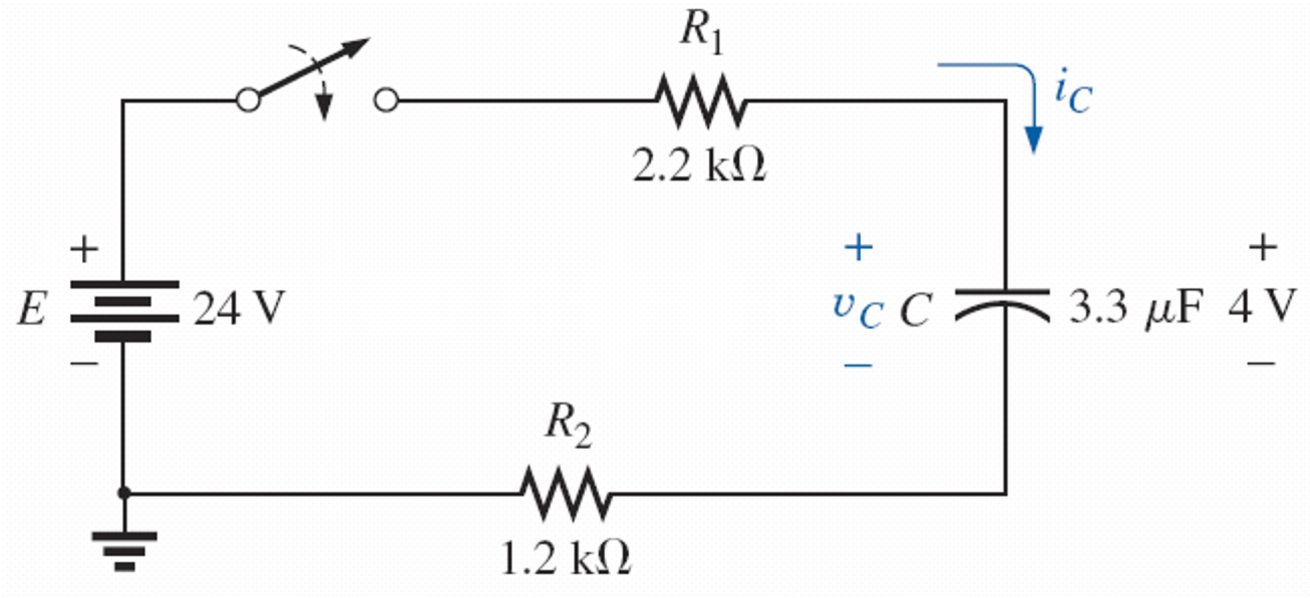


FIG. 10.53
Example 10.10.

INITIAL CONDITIONS

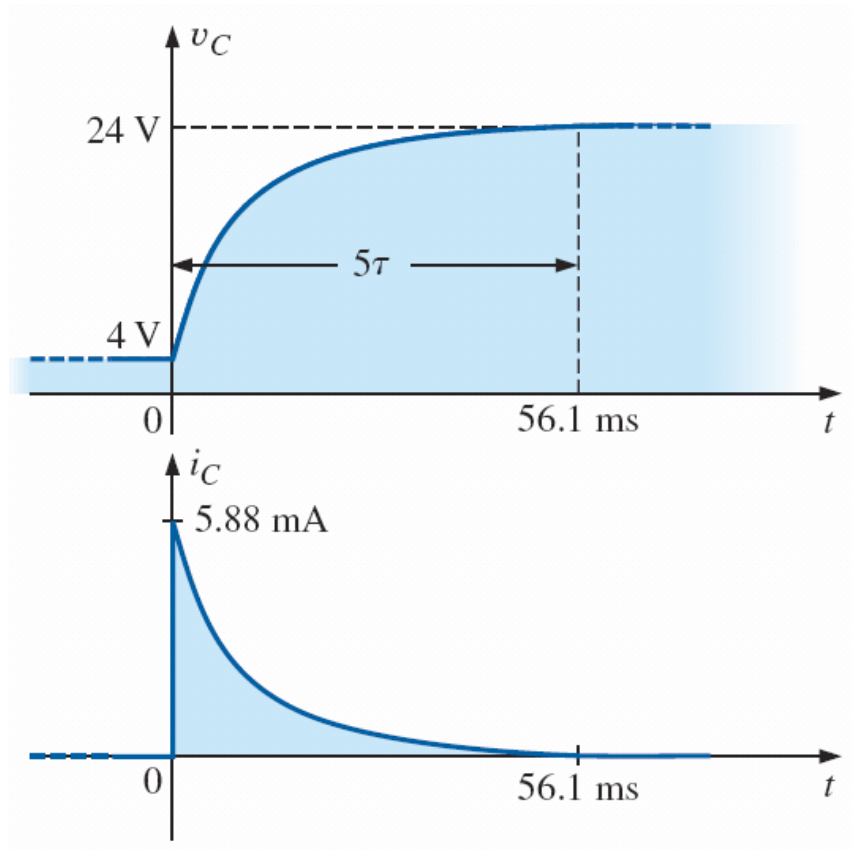


FIG. 10.54 v_C and i_C for the network in Fig. 10.53.

INITIAL CONDITIONS

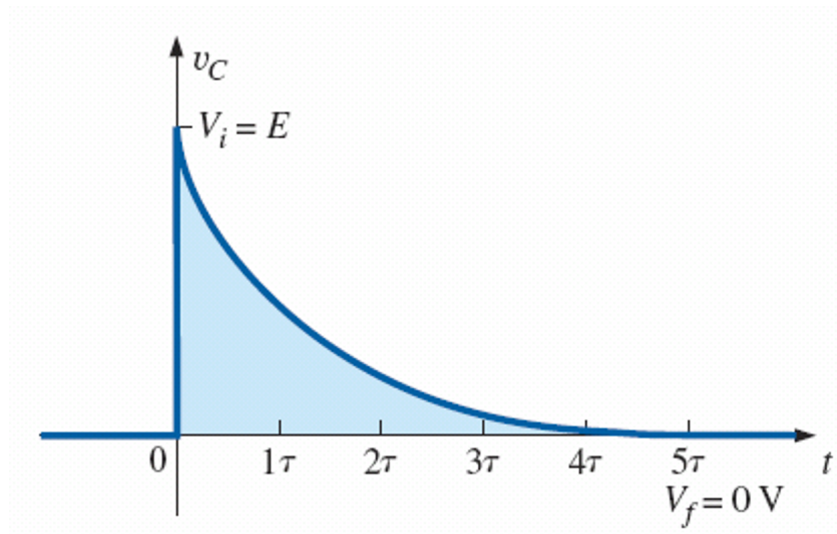


FIG. 10.55 *Defining the parameters in Eq. (10.21) for the discharge phase.*

INSTANTANEOUS VALUES

- Occasionally, you may need to determine the voltage or current at a particular instant of time that is not an integral multiple of t .



2 EE (-) 3 x 2ND LN 2) ENTER 1.39E-3

FIG. 10.56 *Key strokes to determine $(2\text{ ms})(\log_e 2)$ using the TI-89 calculator.*

THÉVENIN EQUIVALENT: $t = RThC$

- You may encounter instances in which the network does not have the simple series form.
- You then need to find the Thévenin equivalent circuit for the network external to the capacitive element.

THÉVENIN EQUIVALENT: $t = RThC$

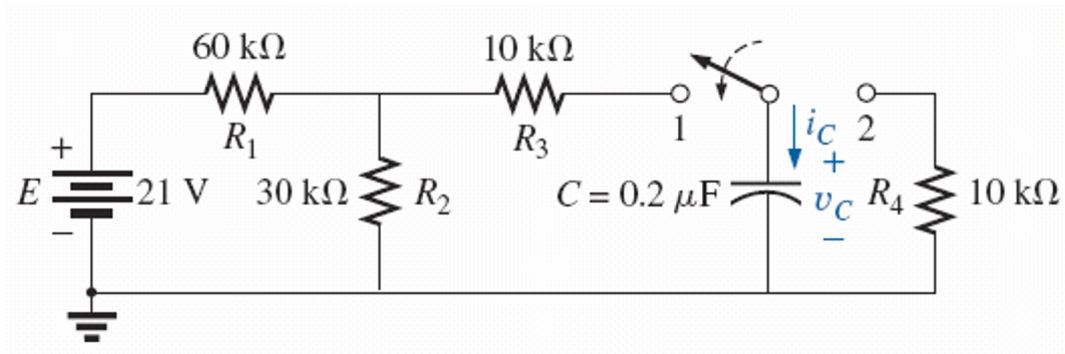


FIG. 10.58
Example 10.11.

THÉVENIN EQUIVALENT: $t = R_{Th}C$

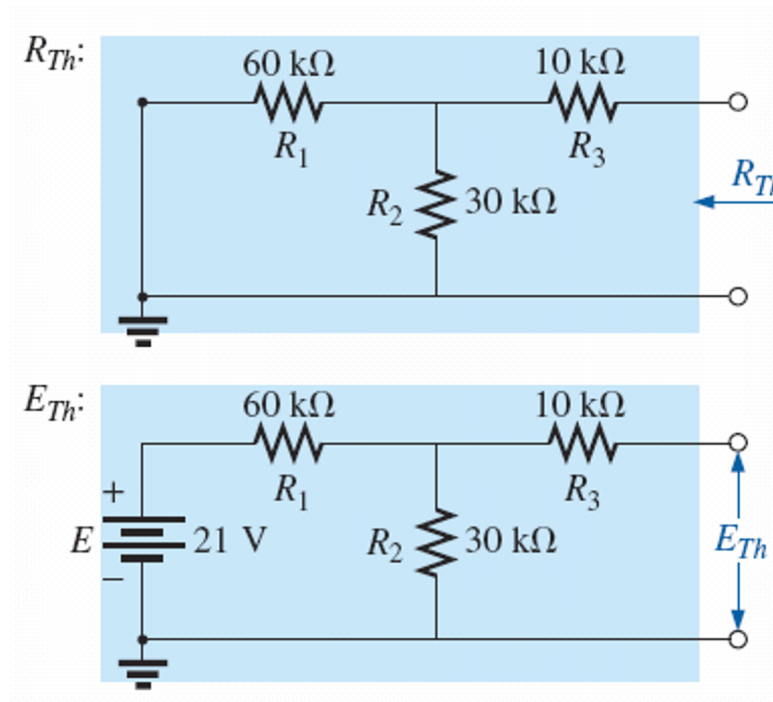


FIG. 10.59 Applying Thévenin's theorem to the network in Fig. 10.58.

THÉVENIN EQUIVALENT: $t = R_{Th}C$

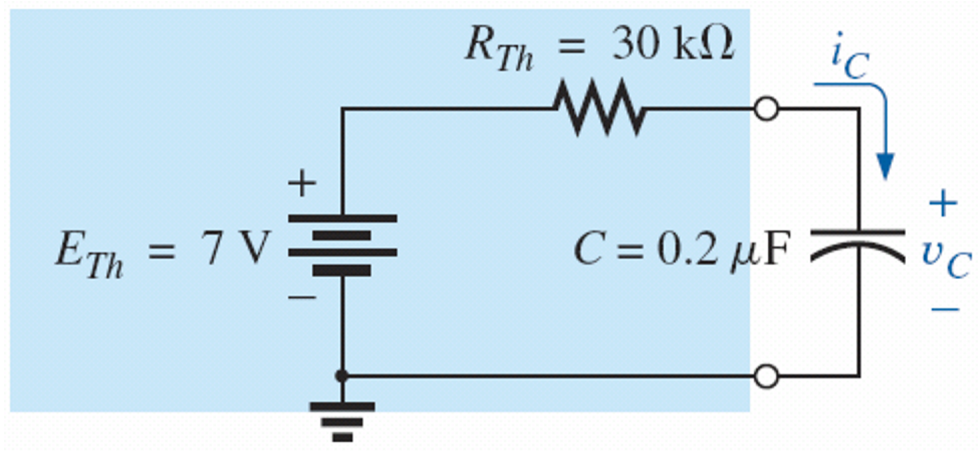


FIG. 10.60 *Substituting the Thévenin equivalent for the network in Fig. 10.58.*

THÉVENIN EQUIVALENT: $t = RThC$

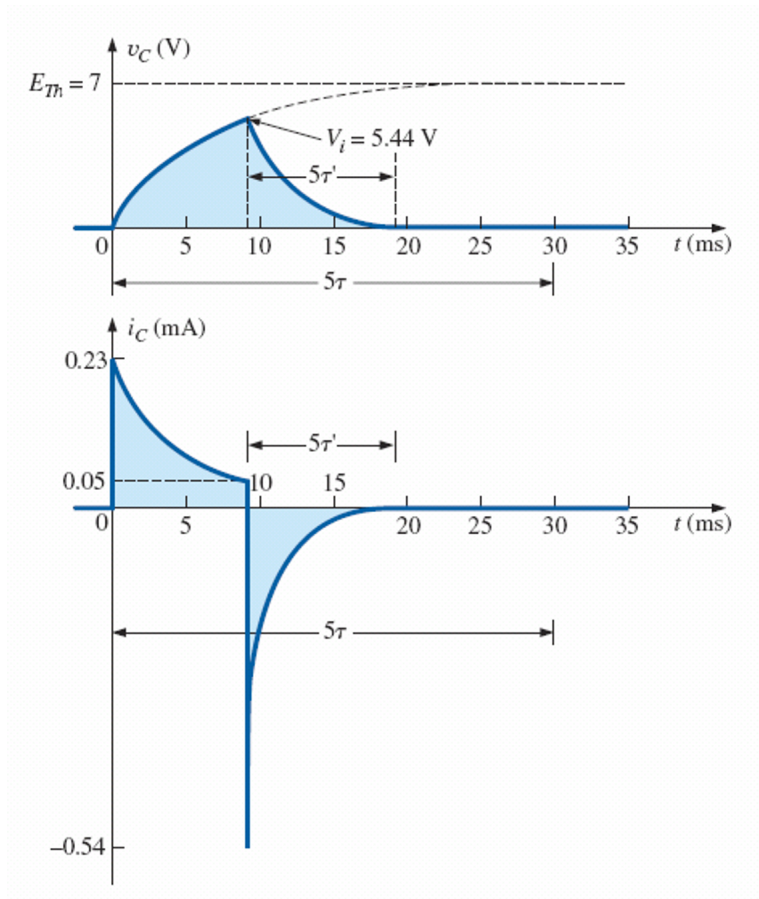


FIG. 10.61 *The resulting waveforms for the network in Fig. 10.58.*

THÉVENIN EQUIVALENT: $t = RThC$

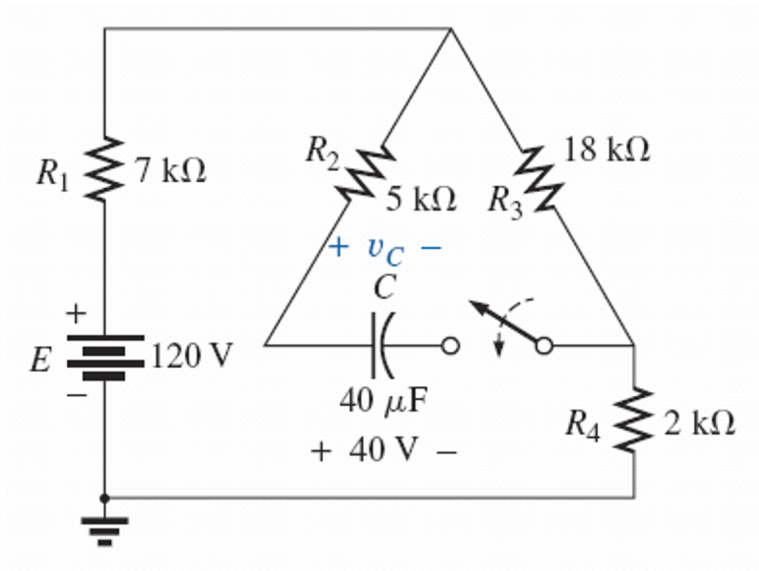


FIG. 10.62
Example 10.12.

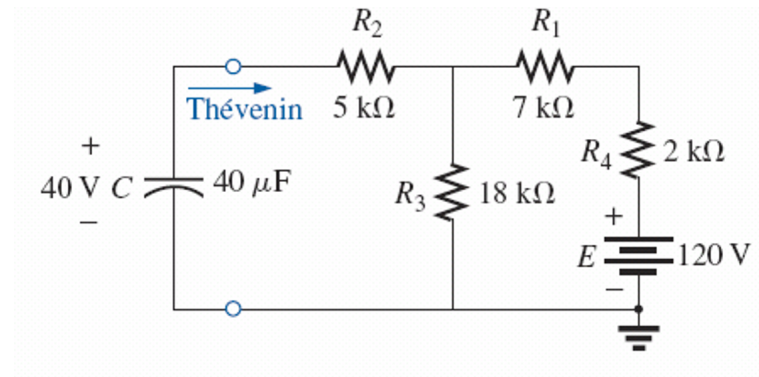


FIG. 10.63 *Network in Fig. 10.62 redrawn.*

THÉVENIN EQUIVALENT: $t = RThC$

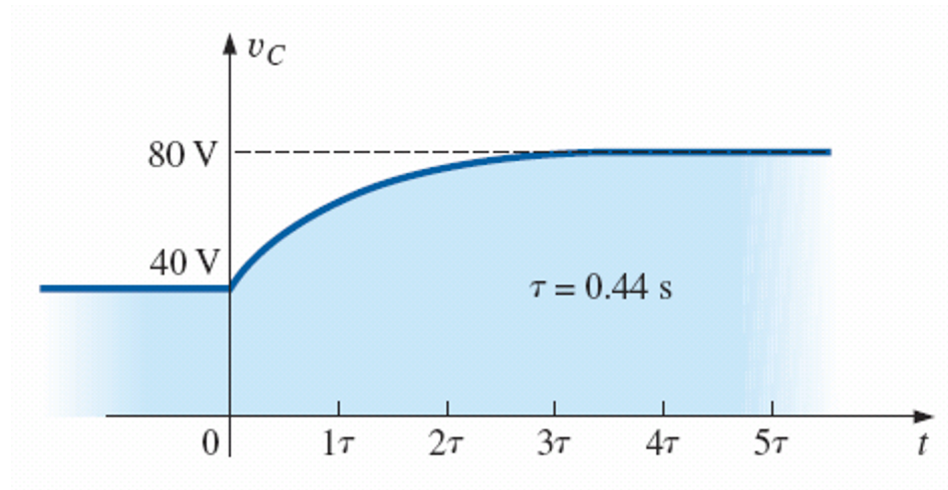


FIG. 10.64 v_C for the network in Fig. 10.62.

THÉVENIN EQUIVALENT: $t = RThC$

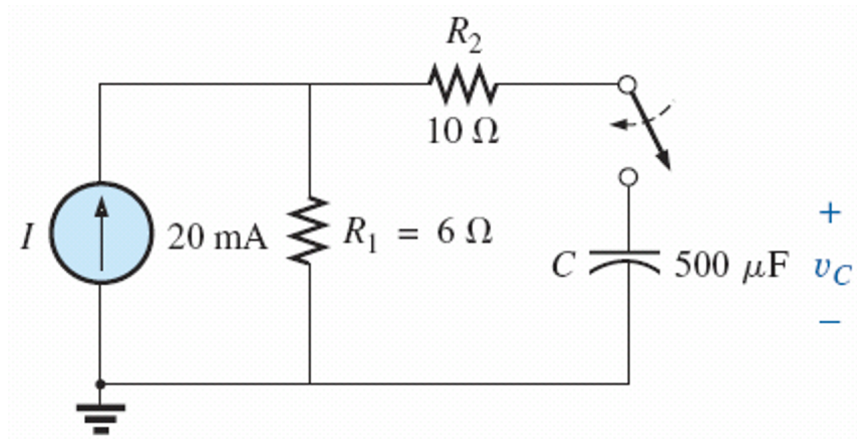


FIG. 10.65
Example 10.13.

THE CURRENT i_C

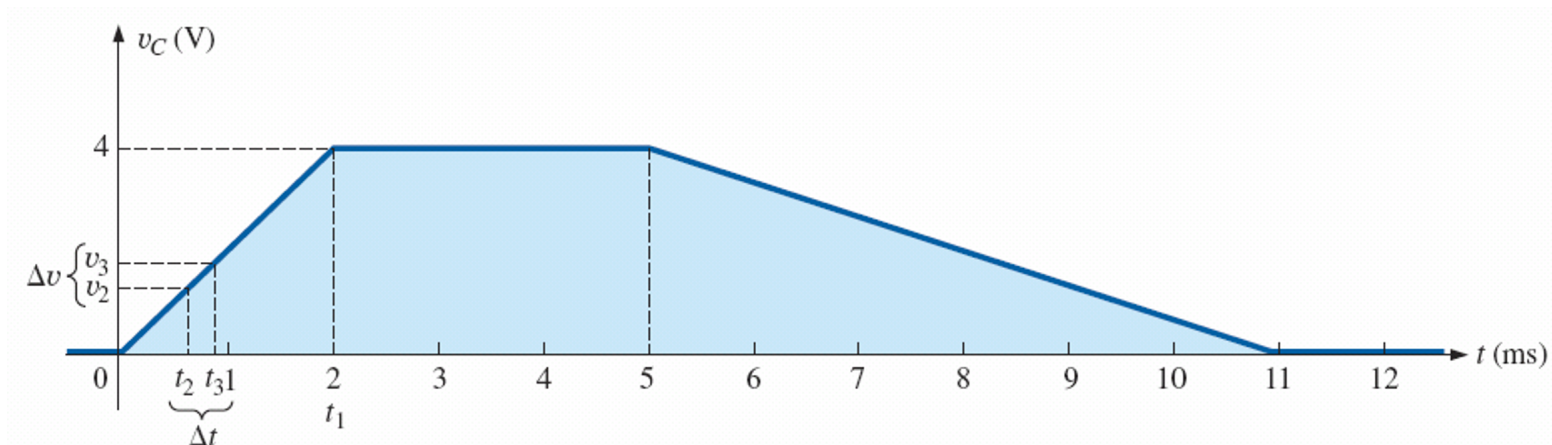


FIG. 10.66 v_C for
Example 10.14.

THE CURRENT i_C

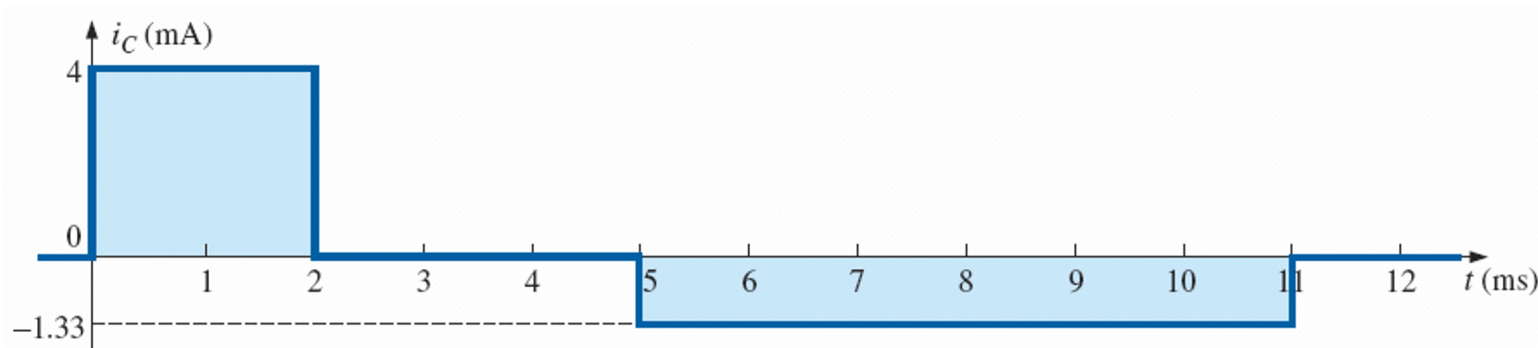


FIG. 10.67 *The resulting current i_C for the applied voltage in Fig. 10.66.*

CAPACITORS IN SERIES AND IN PARALLEL

- Capacitors, like resistors, can be placed in series and in parallel.
- Increasing levels of capacitance can be obtained by placing capacitors in parallel, while decreasing levels can be obtained by placing capacitors in series.

CAPACITORS IN SERIES AND IN PARALLEL

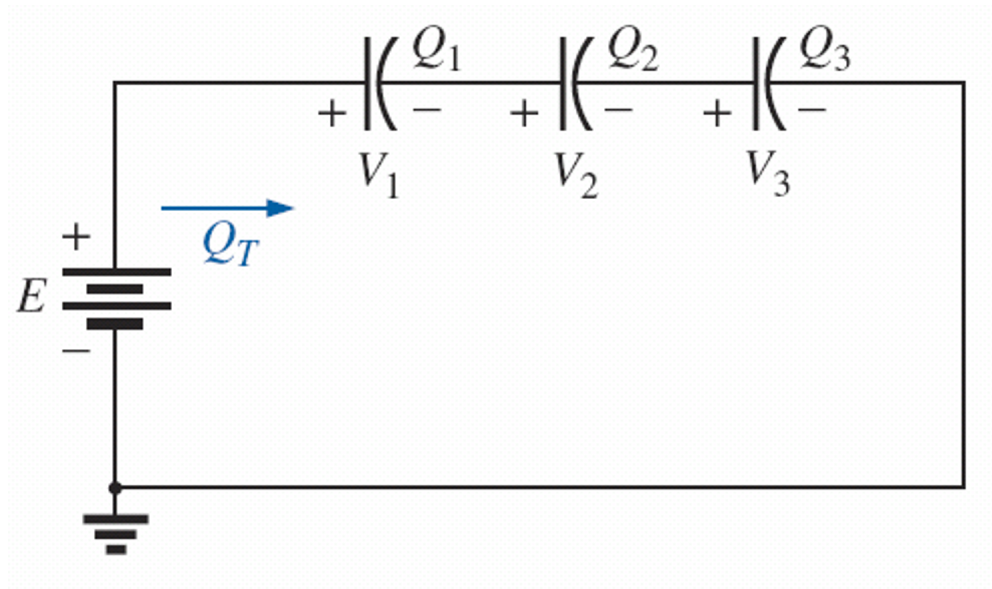


FIG. 10.68 *Series capacitors.*

CAPACITORS IN SERIES AND IN PARALLEL

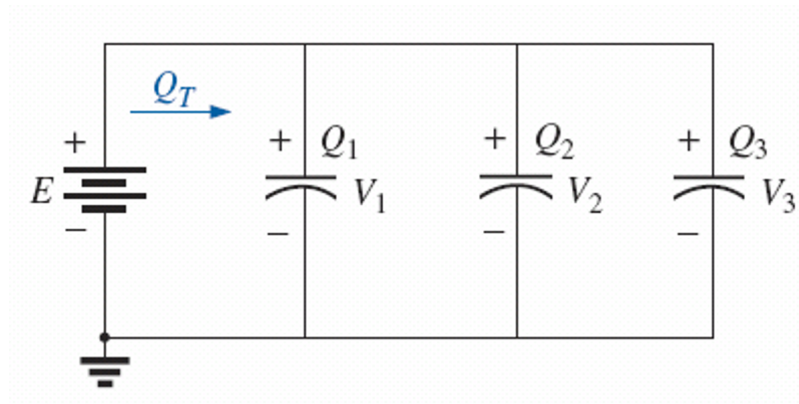


FIG. 10.69

*Parallel
capacitors.*

CAPACITORS IN SERIES AND IN PARALLEL

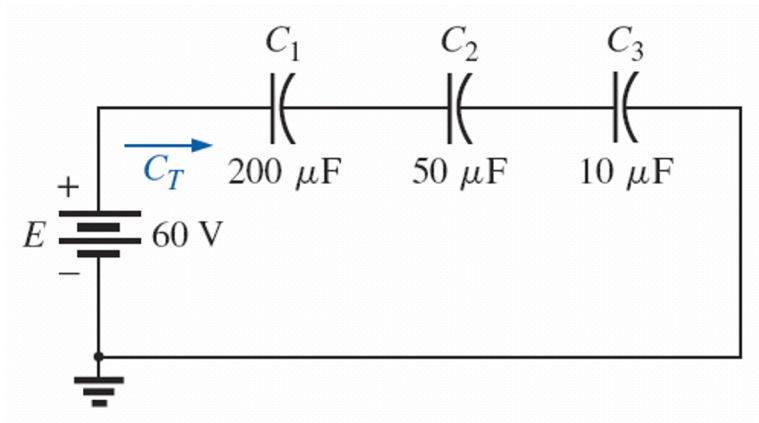


FIG. 10.70
Example 10.15.

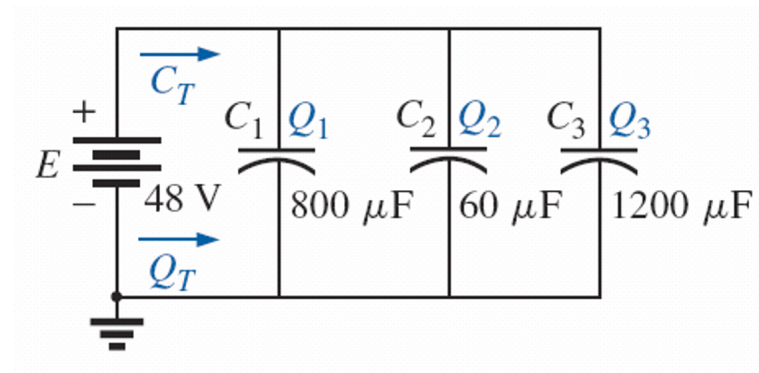


FIG. 10.71
Example 10.16.

CAPACITORS IN SERIES AND IN PARALLEL

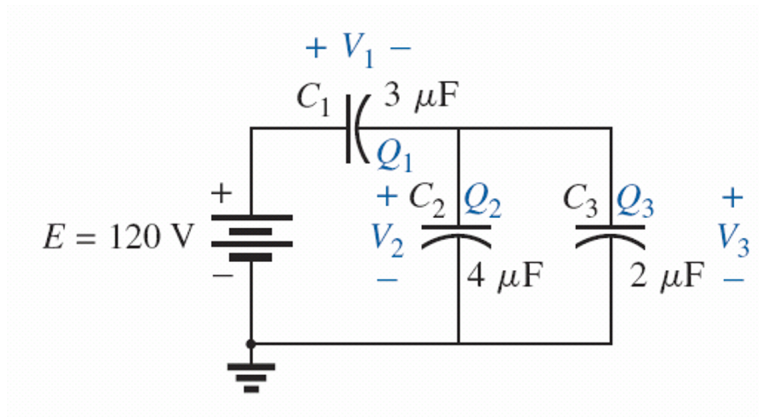


FIG. 10.72

Example 10.17.

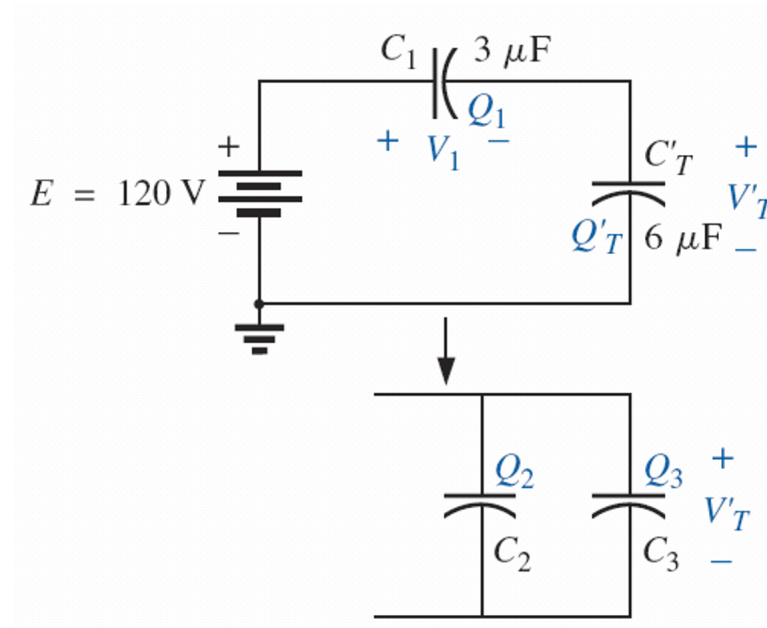


FIG. 10.73 *Reduced equivalent for the network in Fig. 10.72.*

CAPACITORS IN SERIES AND IN PARALLEL

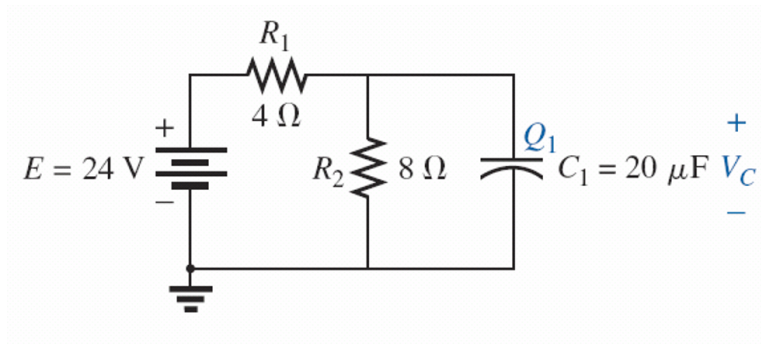


FIG. 10.74
Example 10.18.

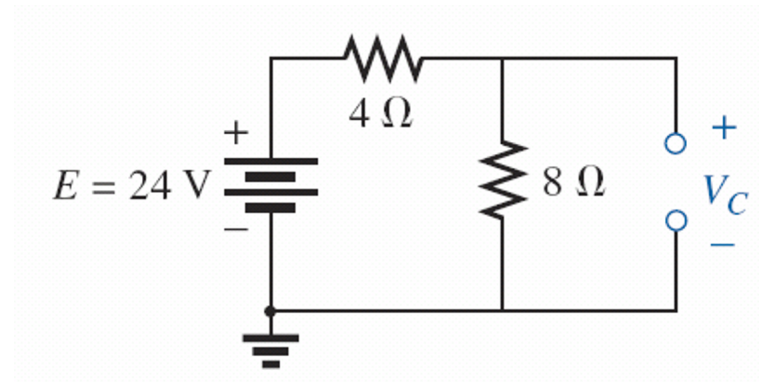


FIG. 10.75
Determining the final (steady-state) value for y_C .

CAPACITORS IN SERIES AND IN PARALLEL

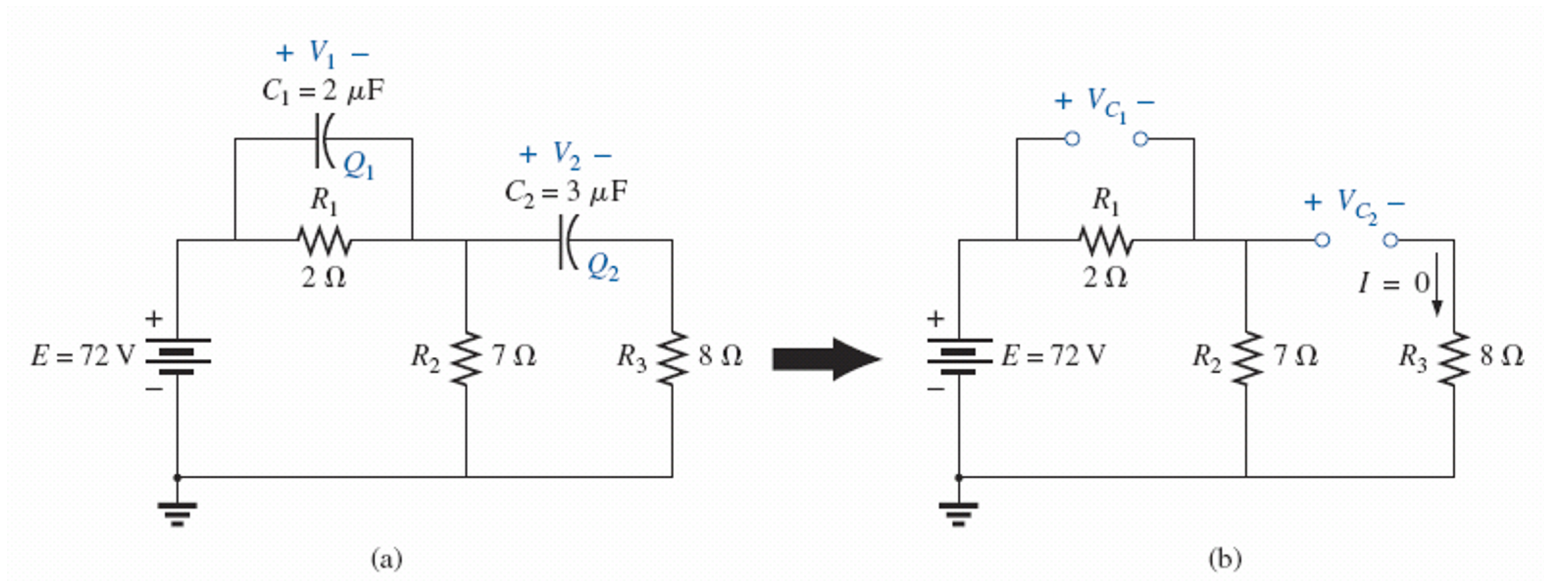


FIG. 10.76
Example 10.19.

ENERGY STORED BY A CAPACITOR

- An ideal capacitor does not dissipate any of the energy supplied to it.
- It stores the energy in the form of an electric field between the conducting surfaces.

ENERGY STORED BY A CAPACITOR

- The power curve can be obtained by finding the product of the voltage and current at selected instants of time and connecting the points obtained.
- The energy stored is represented by the shaded area under the power curve.

ENERGY STORED BY A CAPACITOR

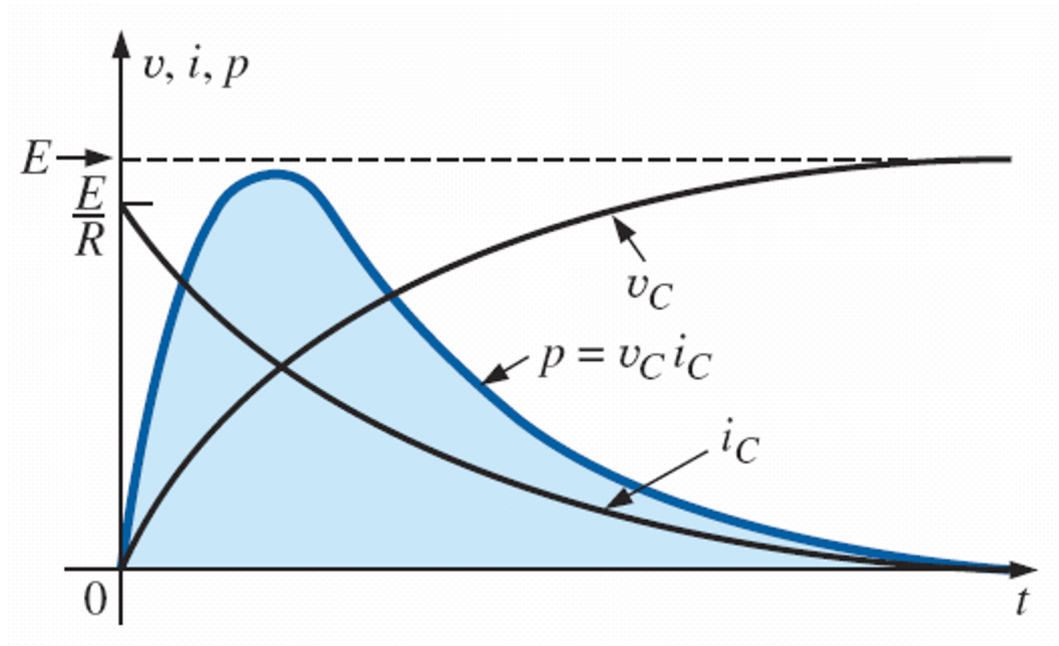


FIG. 10.77 *Plotting the power to a capacitive element during the transient phase.*

STRAY CAPACITANCES

- In addition to the capacitors discussed so far in this chapter, there are stray capacitances that exist not through design but simply because two conducting surfaces are relatively close to each other.
- Two conducting wires in the same network have a capacitive effect between them.

STRAY CAPACITANCES

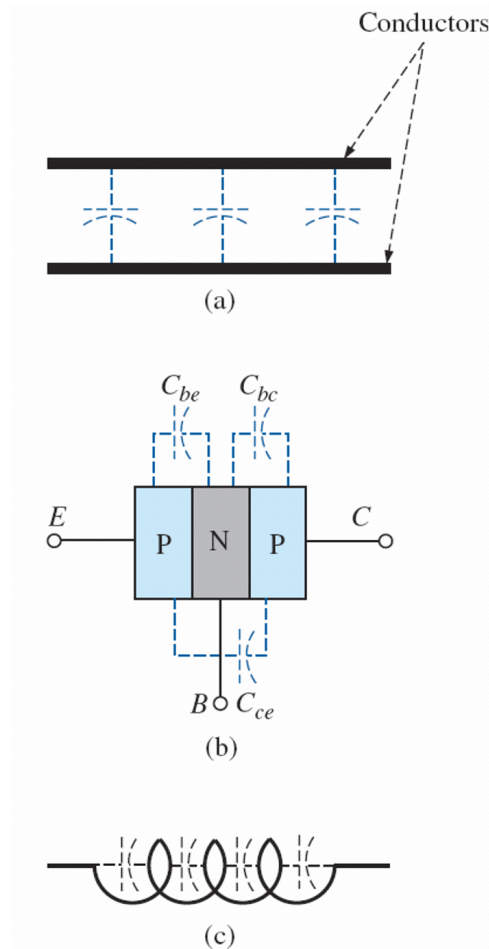


FIG. 10.78
*Examples of
stray
capacitance.*

APPLICATIONS

Touch Pad

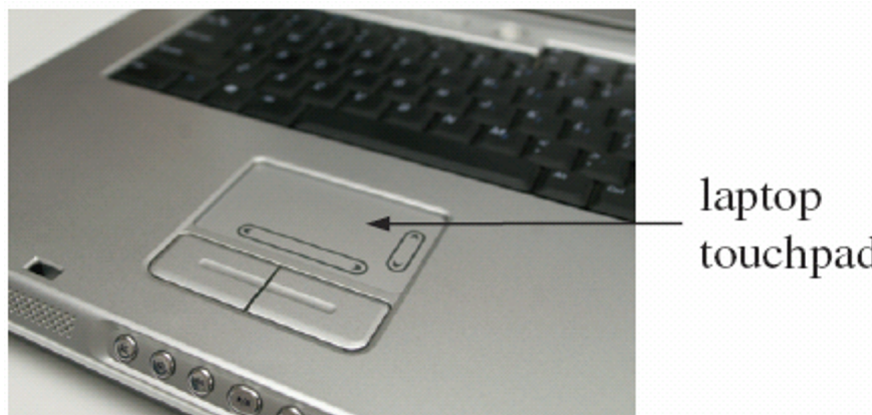


FIG. 10.79
*Laptop touch
pad.*

APPLICATIONS

Touch Pad

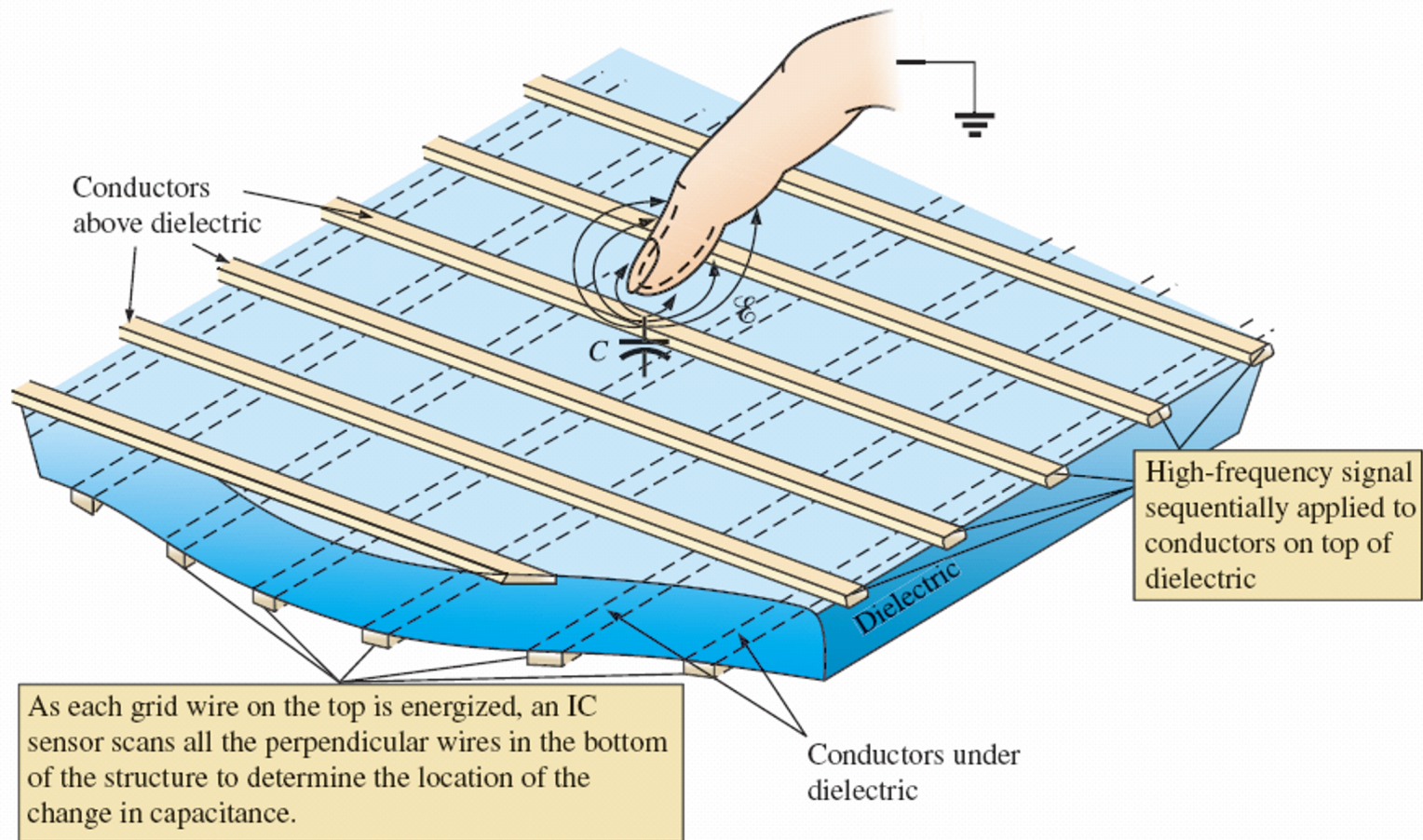


FIG. 10.80 *Matrix approach to capacitive sensing in a touch pad.*

APPLICATIONS

Touch Pad

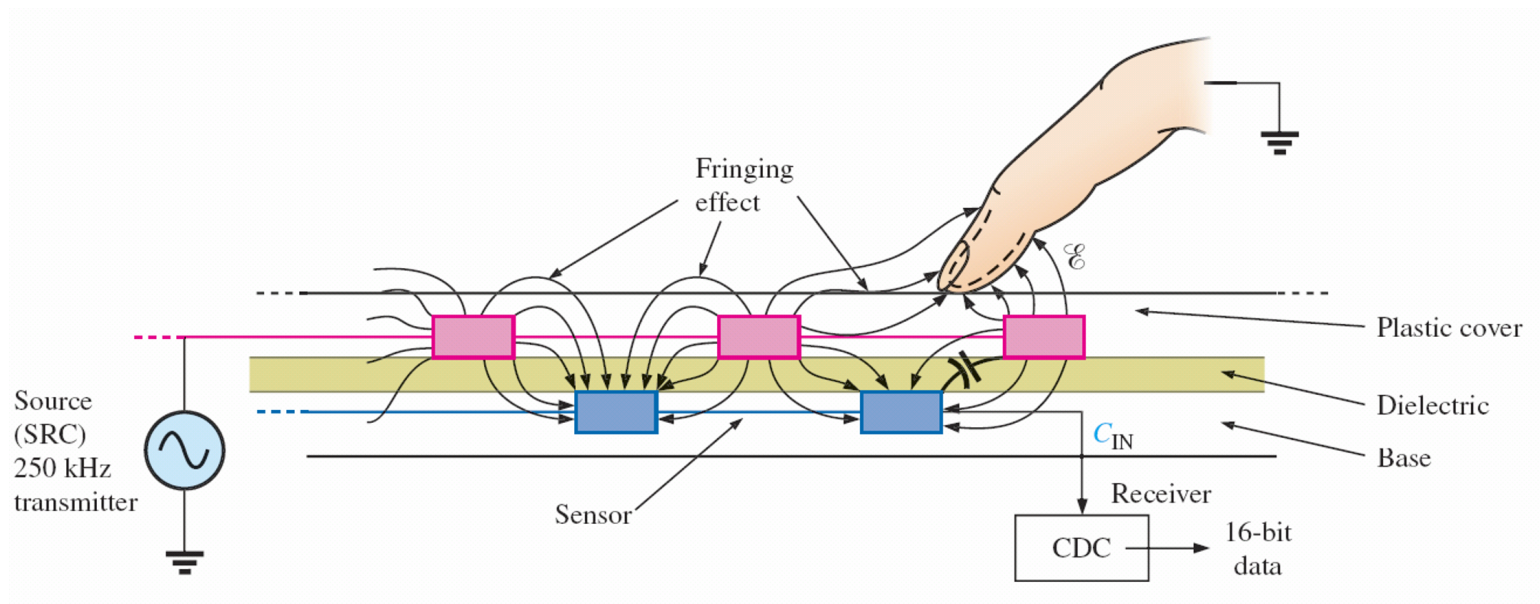


FIG. 10.81 *Capacitive shunt approach.*

APPLICATIONS

Touch Pad

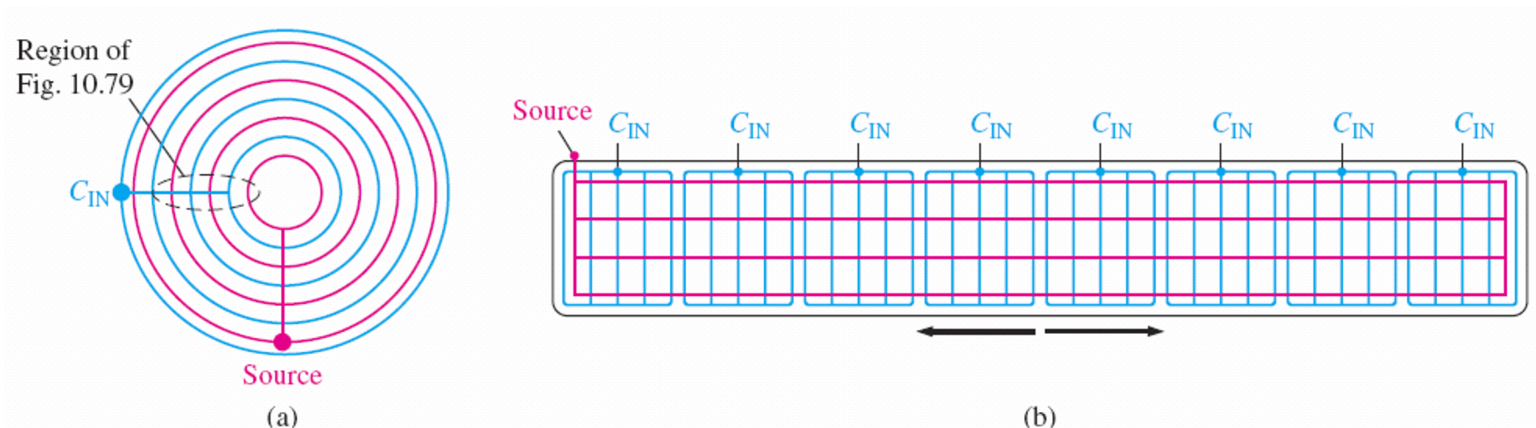


FIG. 10.82 *Capacitive shunt sensors: (a) bottom, (b) slice.*

APPLICATIONS

Surge Protector (Line Conditioner)



FIG. 10.83 *Surge protector: general appearance.*

APPLICATIONS

Surge Protector (Line Conditioner)

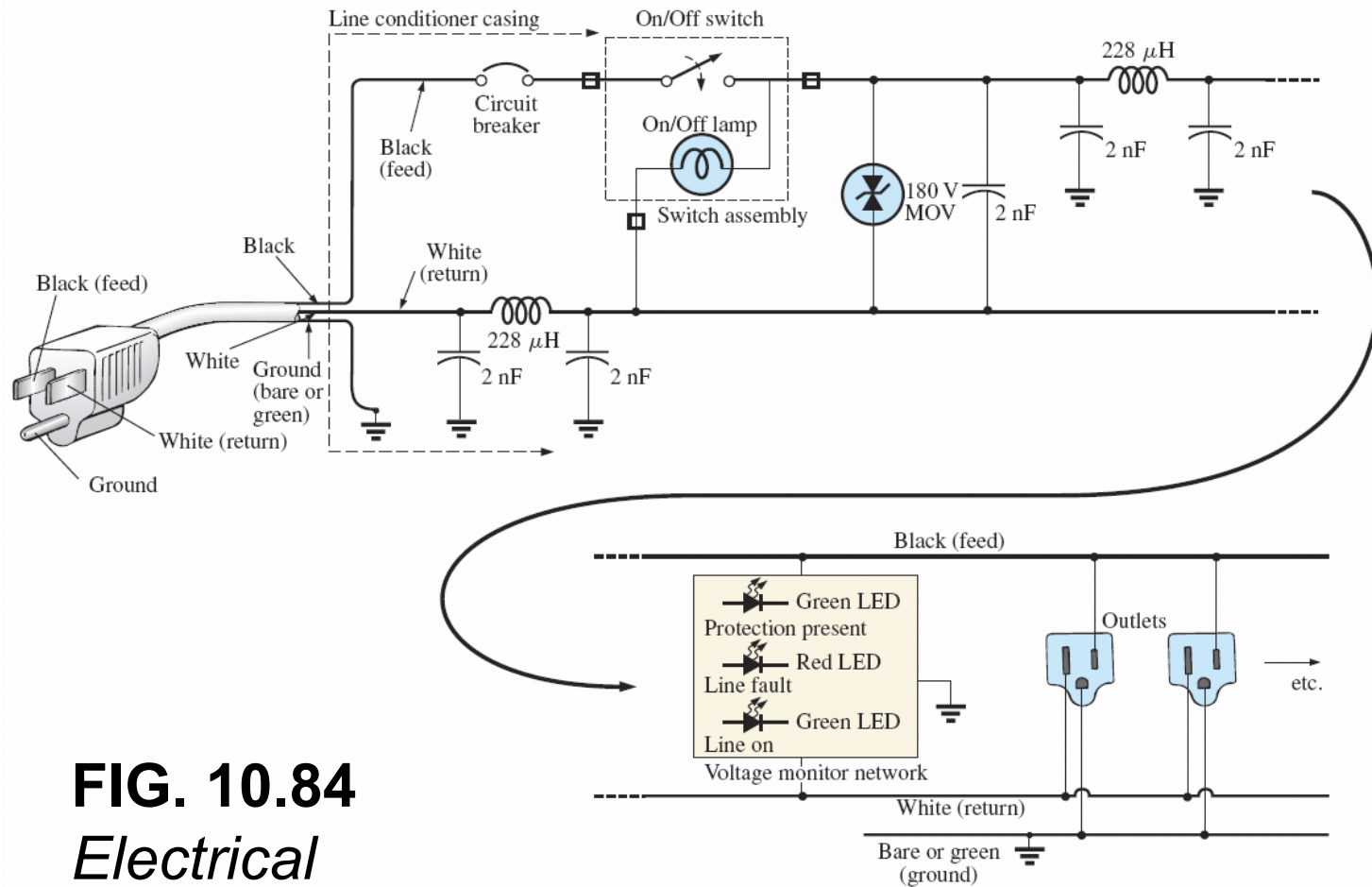


FIG. 10.84
*Electrical
schematic.*

APPLICATIONS

Surge Protector (Line Conditioner)

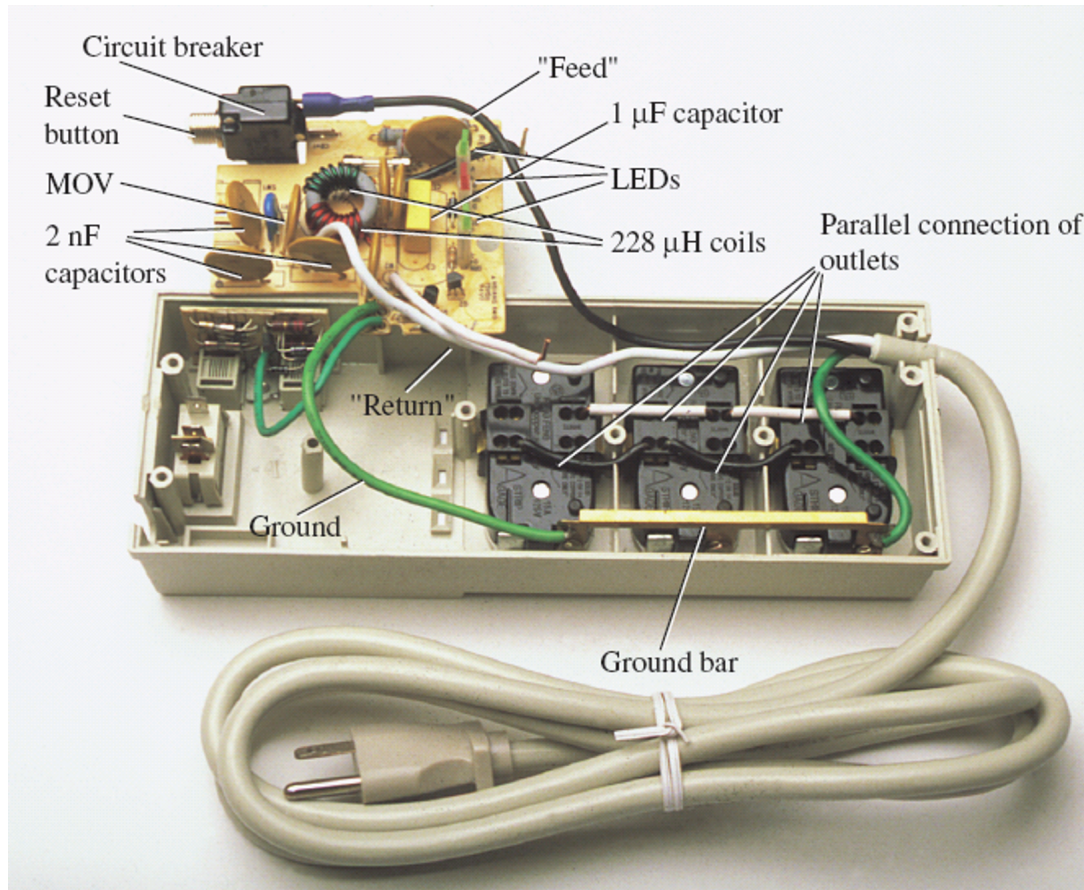


FIG. 10.85 *Internal construction of surge protector.*

COMPUTER ANALYSIS

PSpice

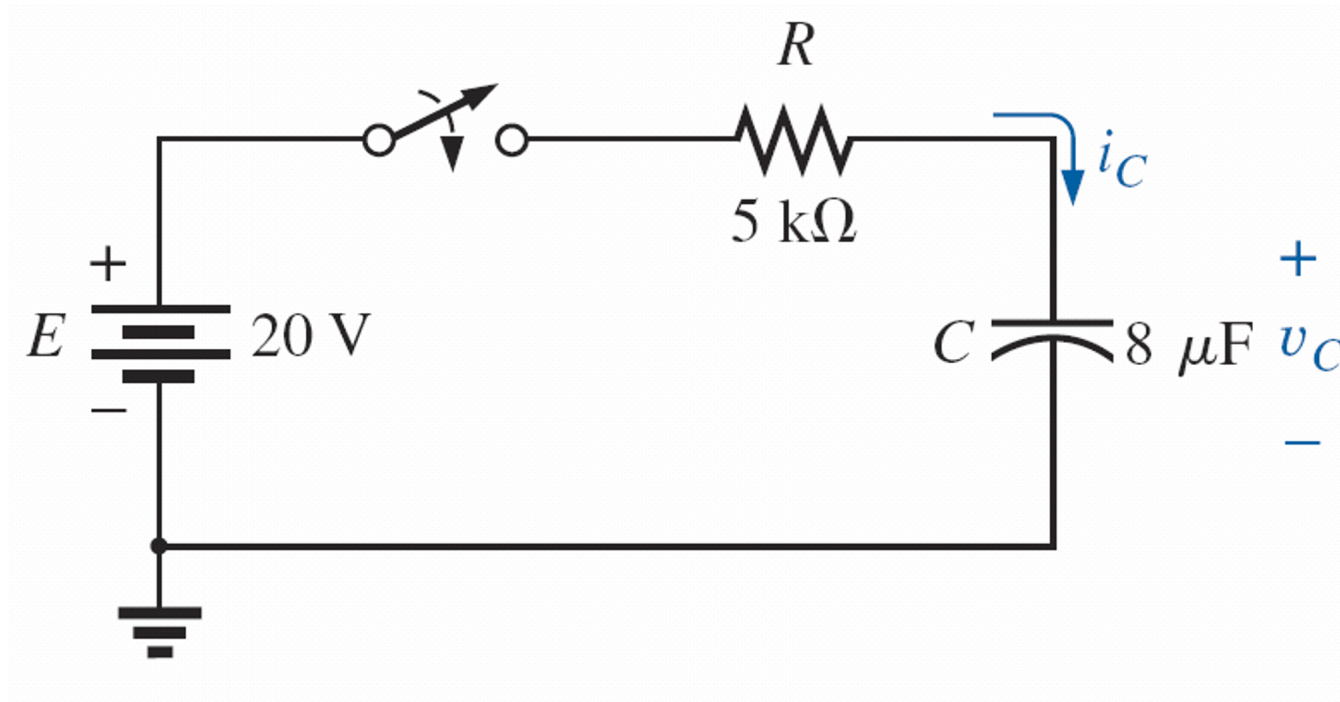


FIG. 10.86 *Circuit to be analyzed using PSpice.*

COMPUTER ANALYSIS

PSpice

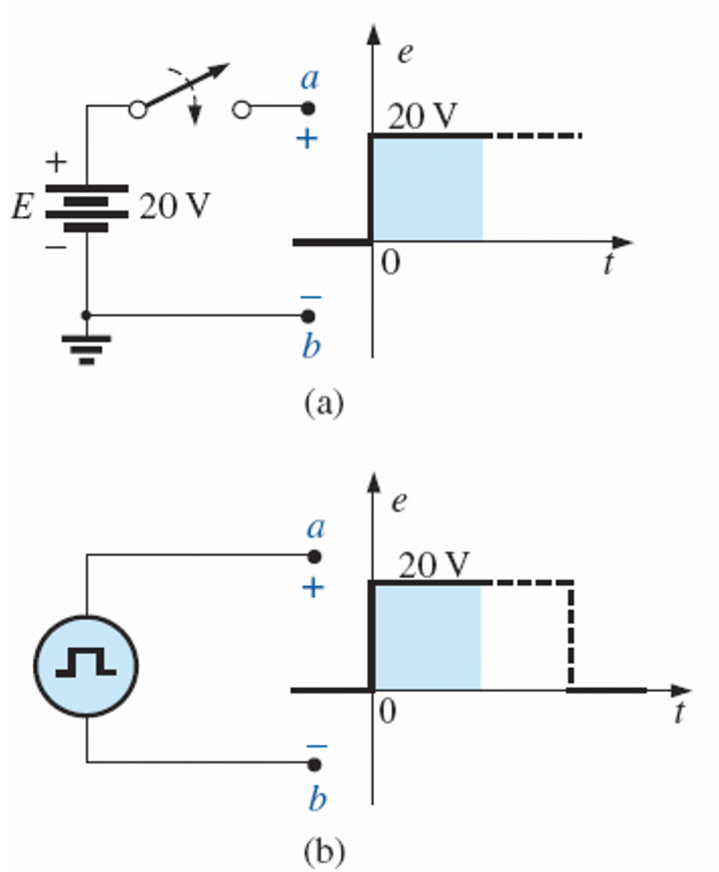


FIG. 10.87

Establishing a switching dc voltage level: (a) series dc voltage-switch combination; (b) PSpice pulse option.

COMPUTER ANALYSIS

PSpice

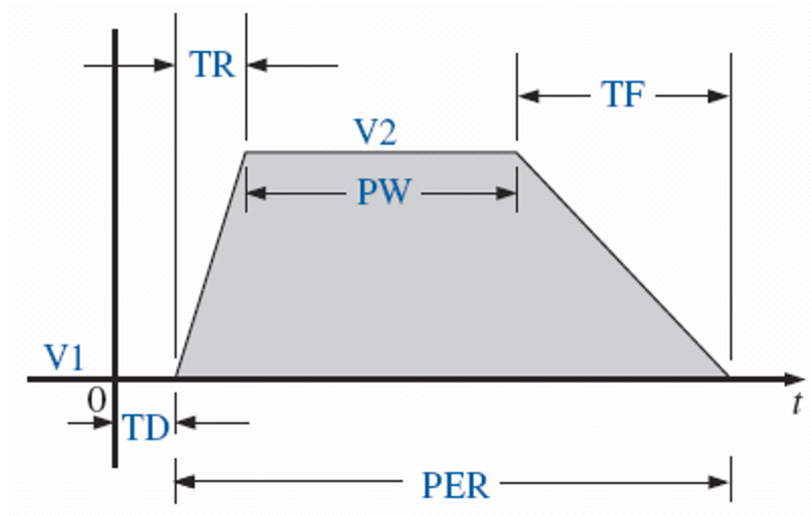


FIG. 10.88 *The defining parameters of PSpice VPulse.*

COMPUTER ANALYSIS

PSpice

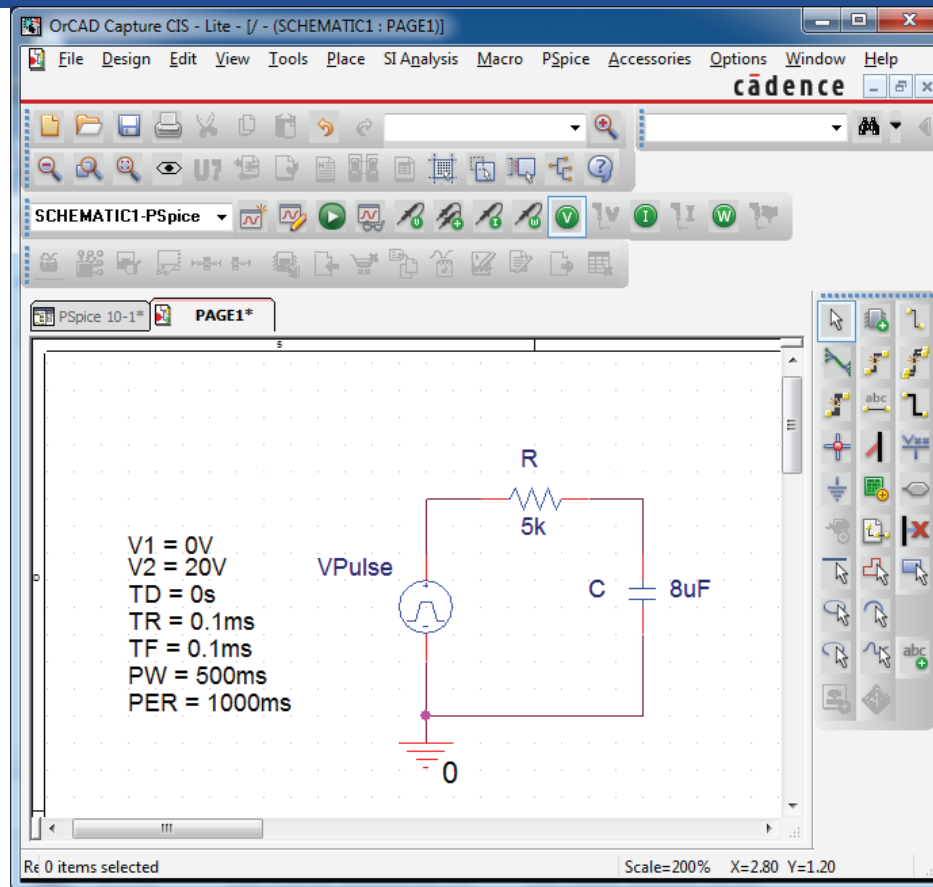
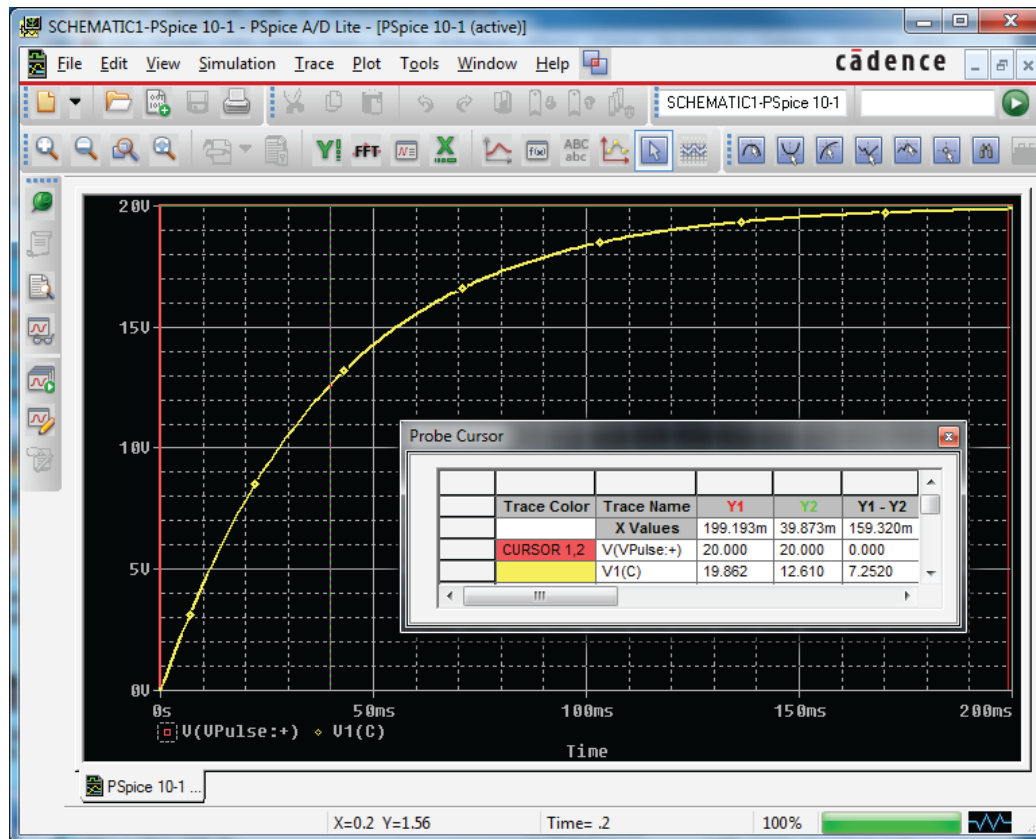


FIG. 10.89 Using PSpice to investigate the transient response of the series R-C circuit in Fig. 10.87.

COMPUTER ANALYSIS

PSpice



10.90 *Transient response for the voltage across the capacitor in Fig. 10.87 when V_{Pulse} is applied.*

COMPUTER ANALYSIS

PSpice

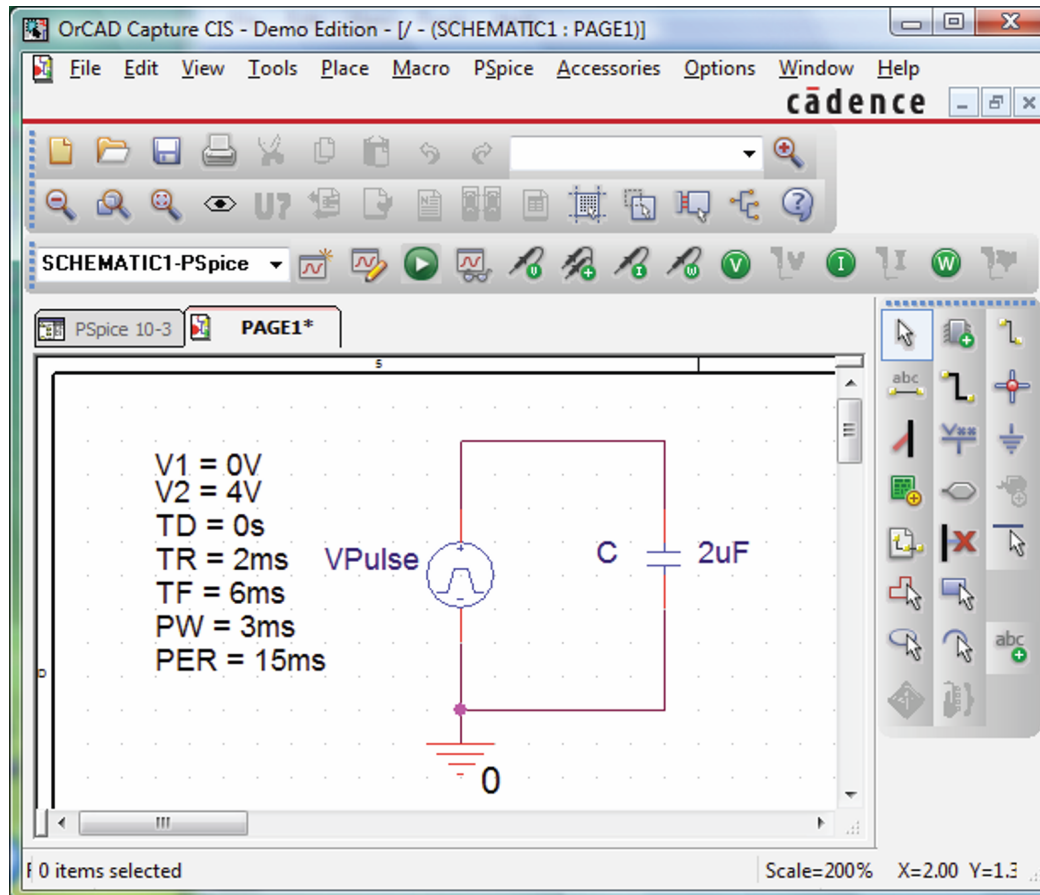


FIG. 10.91 *Using PSpice to verify the results in Example 10.14.*

COMPUTER ANALYSIS

PSpice

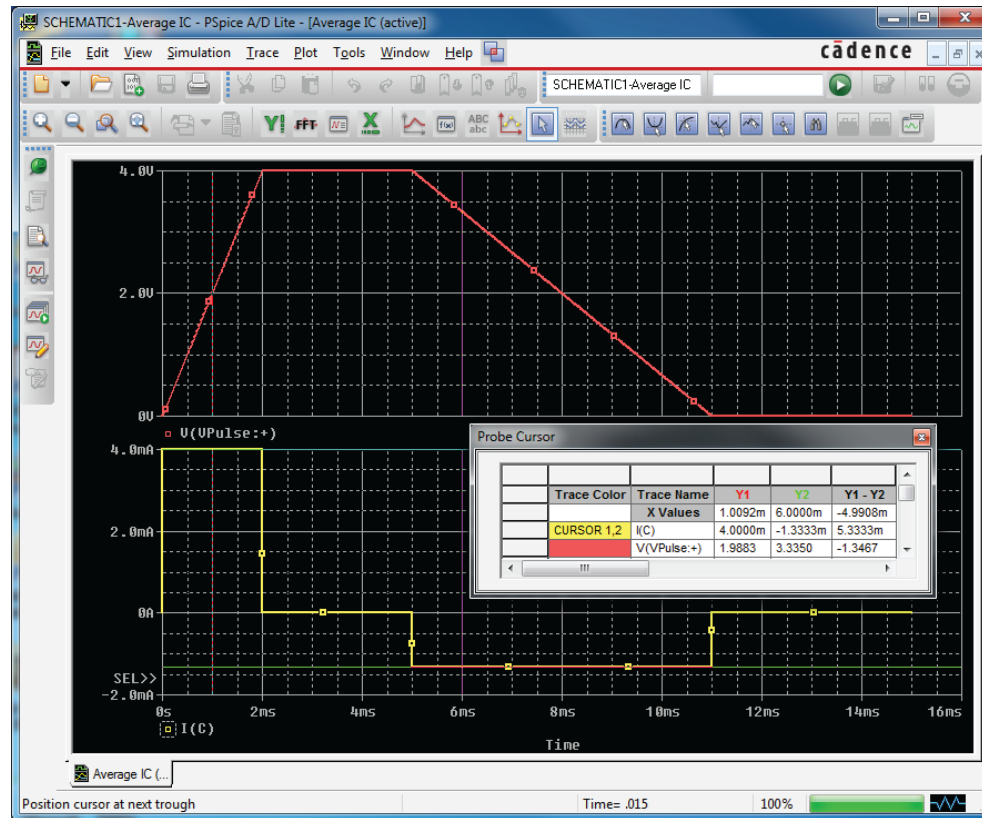


FIG. 10.92 The applied pulse and resulting current for the 2 mF capacitor in Fig. 10.92.

COMPUTER ANALYSIS

Multisim

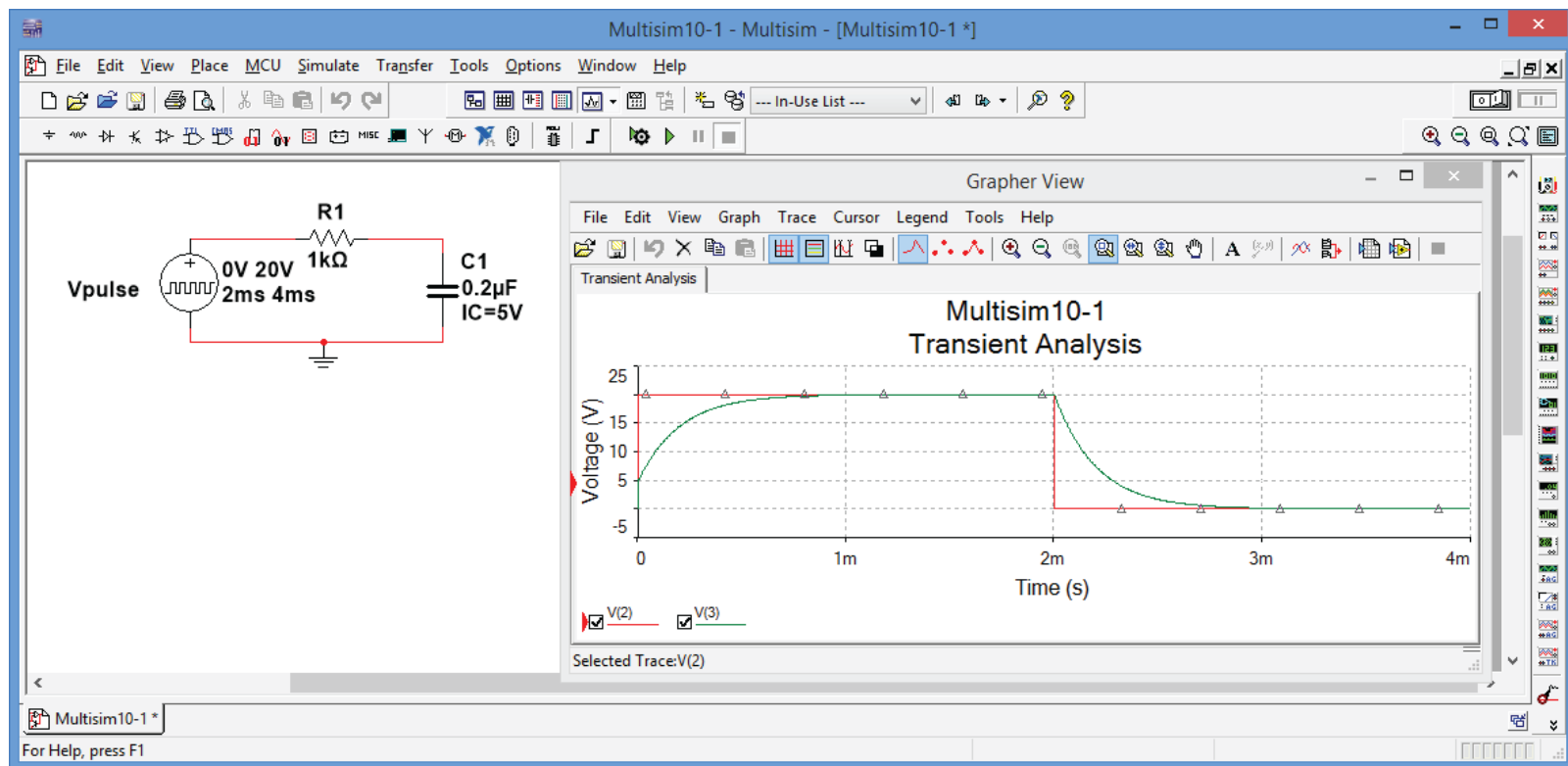


FIG. 10.93 Applying Multisim to determine the response of a series R-C circuit to a pulse signal if the capacitor has an initial voltage to consider.